ENVIRONMENTAL INFORMATION IN SUPPORT OF SITE DESIGNATION DOCUMENTS FOR THE FOUL AREA DISPOSAL SITE

PHYSICAL OCEANOGRAPHY

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I. EXISTING CONDITIONS

This section discusses the physical characteristics of the Foul Area Disposal Site (FADS) and the surrounding environment in terms of its overall setting in the Gulf of Maine and Massachusetts Bay. A thorough review of existing literature relevant to FADS was conducted, and in-situ measurements were made during the summer of 1985 and winter of 1986 to supplement this general information with site specific data.

I.1 Climate

The climate in the vicinity of FADS is influenced by three major factors: the prevailing west to east atmospheric flow, northward and southward fluctuations of tropical and polar air masses on this eastward flow, and the location on the east coast. The first two factors create a relatively high degree of variability in the weather patterns as warm, moist air from the south alternates with cool, dry air from the north. The location near the coast tends to moderate the extremes of temperature because the cool water surface in the summer cools the air, while the relatively warm water in the winter reduces the severity of cold waves. Throughout the year, but particularly during winter, the tracks of low pressure systems (northeasters) frequently follow the coastline, causing rain or snow and gale winds to be a common occurance. Heavy fog occurs on an average of two days per month, and precipitation occurs on the average of one day in every three. A summary of the climatic conditions for the coastline west of the disposal site is presented in Table I.1-1 (U.S. Department of Commerce, 1979).

The wind systems affecting the region adjacent to FADS display a regular seasonal variability. Wind data for the Massachusetts Bay Area summarized in Figure I.1-1 and Table I.1-2 (Raytheon, 1974, Metcalf & Eddy, 1984) indicate that in the winter months (November through March) the dominant wind direction is northwest while during the warmer months the dominant direction is strongly from the southwest. Winds over 25 mph occur most frequently from the northwest between December and March.

These prevailing wind patterns are frequently perturbed throughout the year by the passage of short duration, high energy, low pressure storm events which follow the coastal track described earlier. These systems, typically rich in easterly winds generate the highest velocity winds affecting the area. This effect is shown in Figure I.1-2 (Hays et. al., 1973). The wind rose on the left of the figure presents a yearly average of the data presented in Figure I.1-1 and clearly displays the dominance of northwest and southwest winds, with a very small component from the northeast quadrant. However, the maximum wind velocities shown on the right of the figure indicate that nearly all strong winds (in excess of 40 mph) occur from the northeast and easterly directions.

Table I.1-1

Summary Of Climatic Conditions, Boston, Massachusetts
(U.S. Department Of Commerce, 1979)

			Wind			
Month	Temp °F	Precipitation In Inches	Mean Speed m.p.h.	Direction	Maximum Speed m.p.h.	Direction
J	29.2	3.69	14.2	NW	61	NW
F	30.4	3.54	14.1	WNW	61	NE
M	38.1	4.01	13.9	NW	60	NE
A	48.6	3.49	13.3	WNW	52	NW
M	58.6	3.47	12.2	SW	50	NE
J	68.0	3.19	11.4	SW	40	NW
J	73.3	2.74	10.8	SW	46	N
A	71.3	3.46	10.7	SW	45	SW
S	64.5	3.16	11.2	SW	57	S
O	55.4	3.02	12.1	SW	45	NW
N	45.2	4.51	12.9	SW	54	NE
D	33.0	4.24	13.8	WNW	49	NW
YR	51.3	42.52	12.6	SW	61	NE

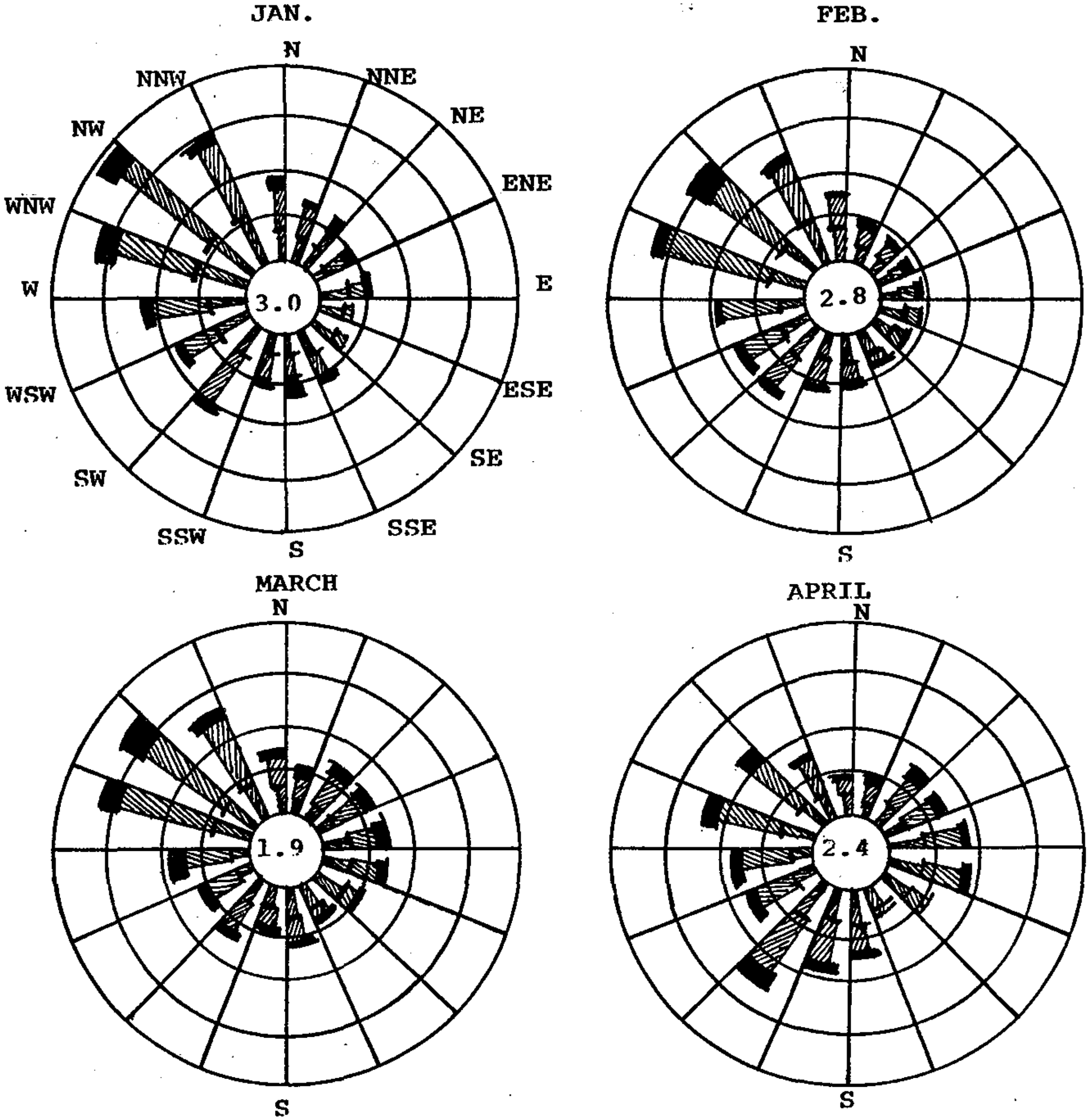

Figure I.1-1a Fifteen year (1950-1964) monthly averaged wind roses from hourly reports at Boston, MA (Logan Airport). Percent calm or near-calm (0-3mph) appears in the central circle and concentric circles represent percentages of 4,8,12 and 16 respectively. Each segment of the 16 wind vector rays depicts the following velocities: inner segment = 4-12mph, middle segment = 13-24mph and outer (solid black) segment = 25mph and over (Massachusetts Weather Bureau).

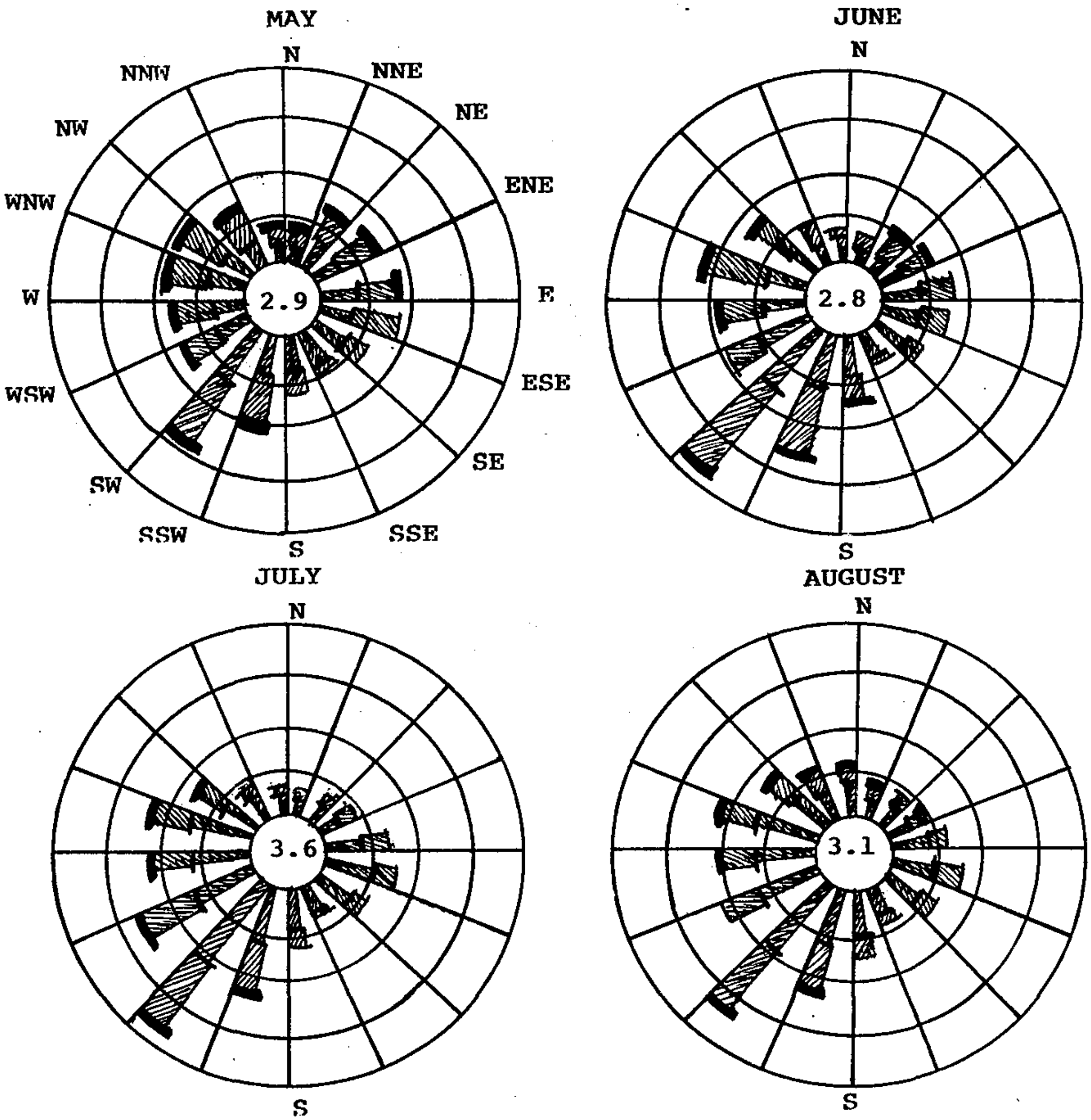

Figure I.1-1b Fifteen year (1950-1964) monthly averaged wind roses from hourly reports at Boston, MA (Logan Airport). Percent calm or near-calm (0-3mph) appears in the central circle and concentric circles represent percentages of 4,8,12 and 16 respectively. Each segment of the 16 wind vector rays depicts the following velocities: inner segment = 4-12mph, middle segment = 13-24mph and outer (solid black) segment = 25mph and over (Massachusetts Weather Bureau).

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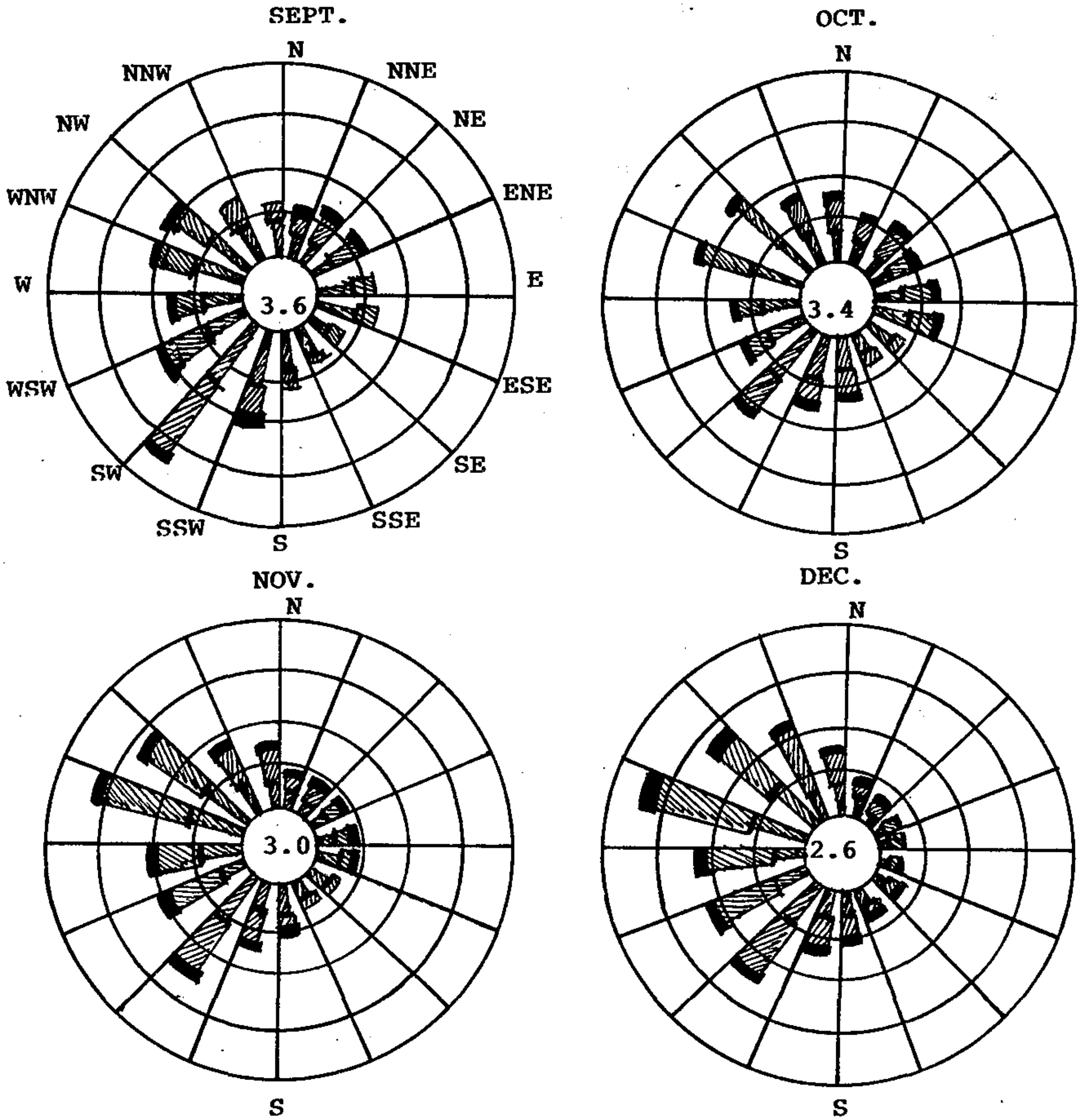


Figure I.1-1c Fifteen year (1950-1964) monthly averaged wind roses from hourly reports at Boston, MA (Logan Airport). Percent calm or near-calm (0-3mph) appears in the central circle and concentric circles represent percentages of 4,8,12 and 16 respectively. Each segment of the 16 wind vector rays depicts the following velocities: inner segment = 4-12mph, middle segment = 13-24mph and outer (solid black) segment = 25mph and over (Massachusetts Weather Bureau).

Table I.1-2

Percent Frequency Of Wind Distribution By Direction And Month
For Massachusetts Bay (Raytheon, 1974).

Dir	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	All Months
N	7.2	5.8	5.2	3.8	3.1	3.1	2.4	4.0	4.7	5.1	5.6	6.4	4.7
NNE	3.4	3.9	4.3	3.6	4.1	3.1	2.3	3.6	4.6	5.4	3.9	3.5	3.8
NE	2.9	3.3	4.8	5.2	5.4	4.0	3.1	4.3	4.7	5.2	3.4	2.4	4.1
ENE	1.9	2.8	4.6	5.7	6.6	4.8	3.6	4.2	4.5	4.1	3.3	2.0	4.0
E	1.6	3.3	5.1	5.9	6.5	5.7	5.3	5.3	4.9	4.7	2.8	1.7	4.4
ESE	1.5	3.1	4.7	6.8	6.7	6.2	6.5	6.4	5.0	4.4	3.0	1.6	4.7
SE	1.9	2.8	3.6	4.5	4.9	4.5	4.8	5.5	4.4	3.5	2.8	1.8	3.7
SSE	2.5	3.0	3.0	3.1	3.3	3.5	3.5	3.8	3.5	2.9	2.8	2.2	3.1
S	3.3	3.8	3.7	4.8	5.2	5.0	5.3	5.2	4.6	4.3	4.0	4.0	4.4
SSW	5.0	4.7	5.4	8.2	9.0	10.6	10.5	9.0	8.5	7.1	6.4	5.1	7.5
SW	8.6	6.5	6.7	9.0	11.0	15.3	15.0	13.0	12.9	11.8	11.0	10.3	10.9
WSW	7.6	6.7	5.3	5.7	6.0	8.0	9.5	8.0	7.1	7.3	6.9	8.9	7.3
W	10.1	9.2	8.1	7.0	6.7	7.0	8.5	7.7	6.1	7.3	9.1	10.4	8.1
WNW	15.1	16.4	12.3	10.5	8.5	8.1	9.3	8.7	8.6	9.6	13.5	16.8	11.4
NW	15.8	13.7	13.1	9.5	7.4	6.3	6.0	6.0	8.6	9.1	12.3	13.6	10.1
NNW	10.9	10.4	9.7	6.4	4.8	4.1	3.6	4.7	6.7	7.3	8.3	8.7	7.1
Calm	0.7	0.6	0.4	0.4	0.7	0.7	0.7	0.6	0.7	0.9	0.9	0.5	0.7
MEAN Speed Knots	12.4	12.6	12.8	12.3	11.1	10.2	9.6	9.5	9.9	10.6	11.6	12.1	11.2

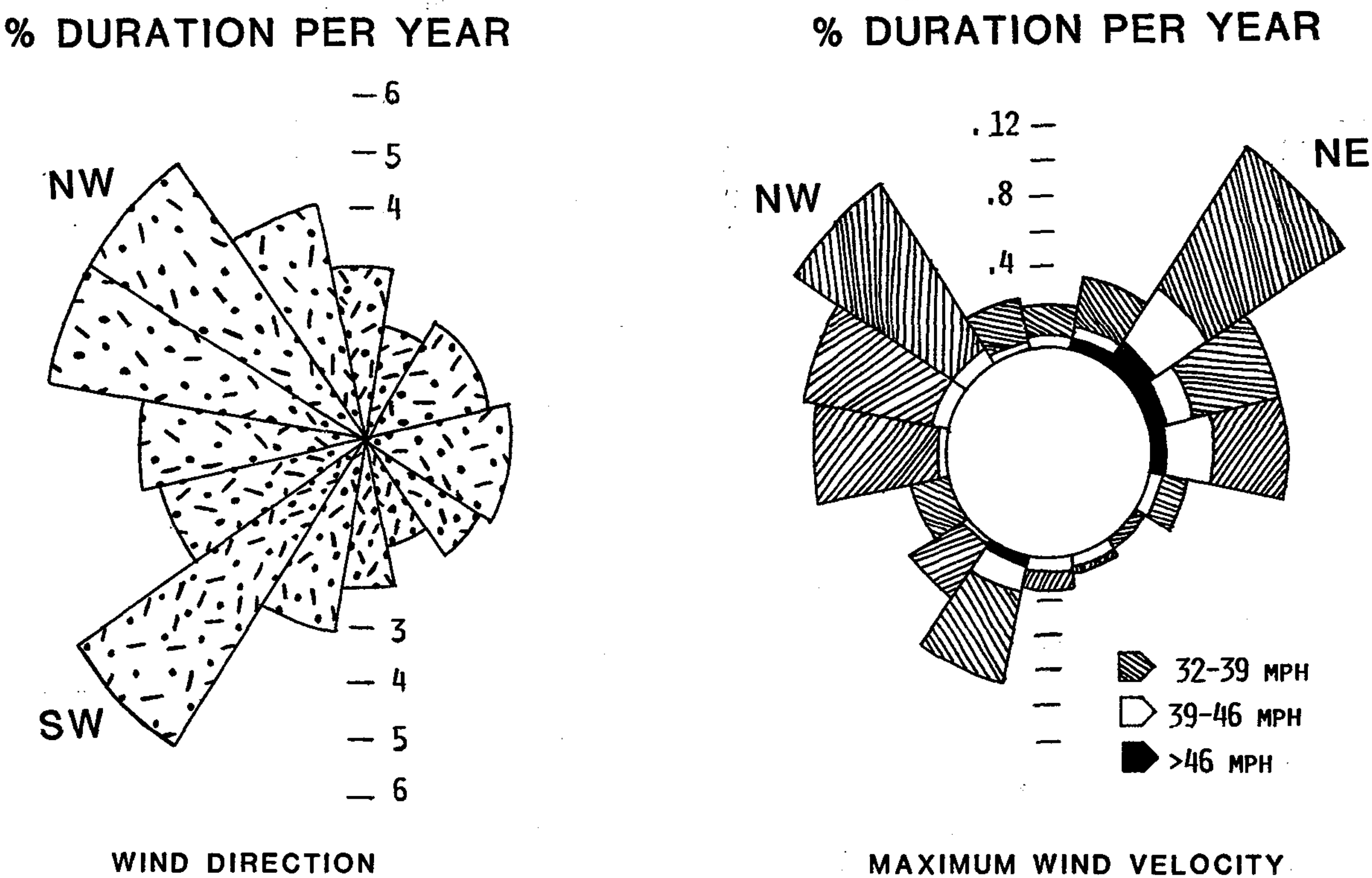


Figure I.1-2. Characterization of Massachusetts Bay wind conditions. (Hayes, Hubbard and Fitzgerald, 1973.)

In addition to these strong wind events that occur on a regular basis, occasional major storms follow a similar track, passing over the region and generating extremely high winds from the east and northeast. A listing of these major storms over a 60 year period from 1920-1980 is presented in Table I.1-3 (Bohlen, 1981). The frequency of occurance of these storms is highly variable, but an average of one major event every three to five years should be expected.

In terms of impact to the disposal site, the easterly storm events are certainly the most significant climatic factors. Not only can they drastically curtail dredging and disposal operations, especially during the winter months, but because the easterly winds are strongest, they have the most potential for generating significantly larger waves. This is particularly important for FADS; the easterly exposure to the open ocean combined with the closeness of the Massachusetts coast to the west provides no fetch limitation to generation of waves from the east, and as will be described later, creates a mechanism for storm induced bottom current flow away from the coast in response to sea level setup in the shallow water.

The wave conditions in the vicinity of FADS result from both local wind wave formation and propagation of long period waves (swell) generated on the adjoining continental shelf. The most pertinent wave data in the vicinity of FADS were summarized by Raytheon Company (1974) as shown in Figure I.1-3 and Table I.1-4. The sheltering provided by the coastline severely limits wave generation from the westerly direction; waves from the westerly quadrants larger than 1.8 m (6 ft) occur only 0.5% of the time on an annual basis, and waves over 3.7 m (12 ft) are virtually nonexistent. Conversely, waves from the easterly quadrant that are over 1.8 m (6 ft) occur 4.2% of the time, or nearly ten times more frequently, and waves over 3.7 m (12 ft) occur approximately 0.5% of the year.

Raytheon (1974) also obtained in-situ wave measurements at 42°26'N,70°43'W, approximately 6NM west of FADS during March and April 1974. These data are presented in Figure I.1-4. The importance of the easterly component is also demonstrated by these data; only the easterly wind events associated with 21 and 30 March generate significant waves in excess of 0.5m, although comparable wind speeds from the northwest occurred from 25 to 28 March.

The small, long period waves occurring on 24 and 25 March are characteristic of ocean swell generated at some distance from the site and propagated westward across Massachusetts Bay. The swell condition is demonstrated by the long period (14-16 sec) and low wave height (less than 0.5m) during periods of low wind velocity (12 mph).

Table I.1-3

Easterly Storms in Massachusetts Bay
(Bohlen, 1981)

Date	FASTEST MILE Maximum Wind Speed (mph)	FASTEST MILE Direction	Observed Change In Sea Level In Boston Harbor (m)
November 23, 1920	59	NE	
April 9, 1935	63	NE	
November 17, 1935	60	NE	
November 5, 1939	62	NE	
September 14,1944	72	NE	
November 30, 1944	66	NE	2.8
November 29, 1945	68	NE	
March 3, 1947	73	NE	
November 7, 1953	67	NE	
April 8, 1956	58	ENE	2.6
February 4, 1961	49	ENE	
September 21, 1961	45	NE	
September 28, 1962	47	NE	
December 24, 1966	47	NE	
May 25, 1967	50	NE	2.7
November 12, 1968	54	NE	
November 8, 1972	48	NE	
March 22, 1977	60	NE	
May 9, 1977	44	NE	
February 6, 1978	61	NE	
January 25, 1979	45	E	
October 25, 1980	48	SE	

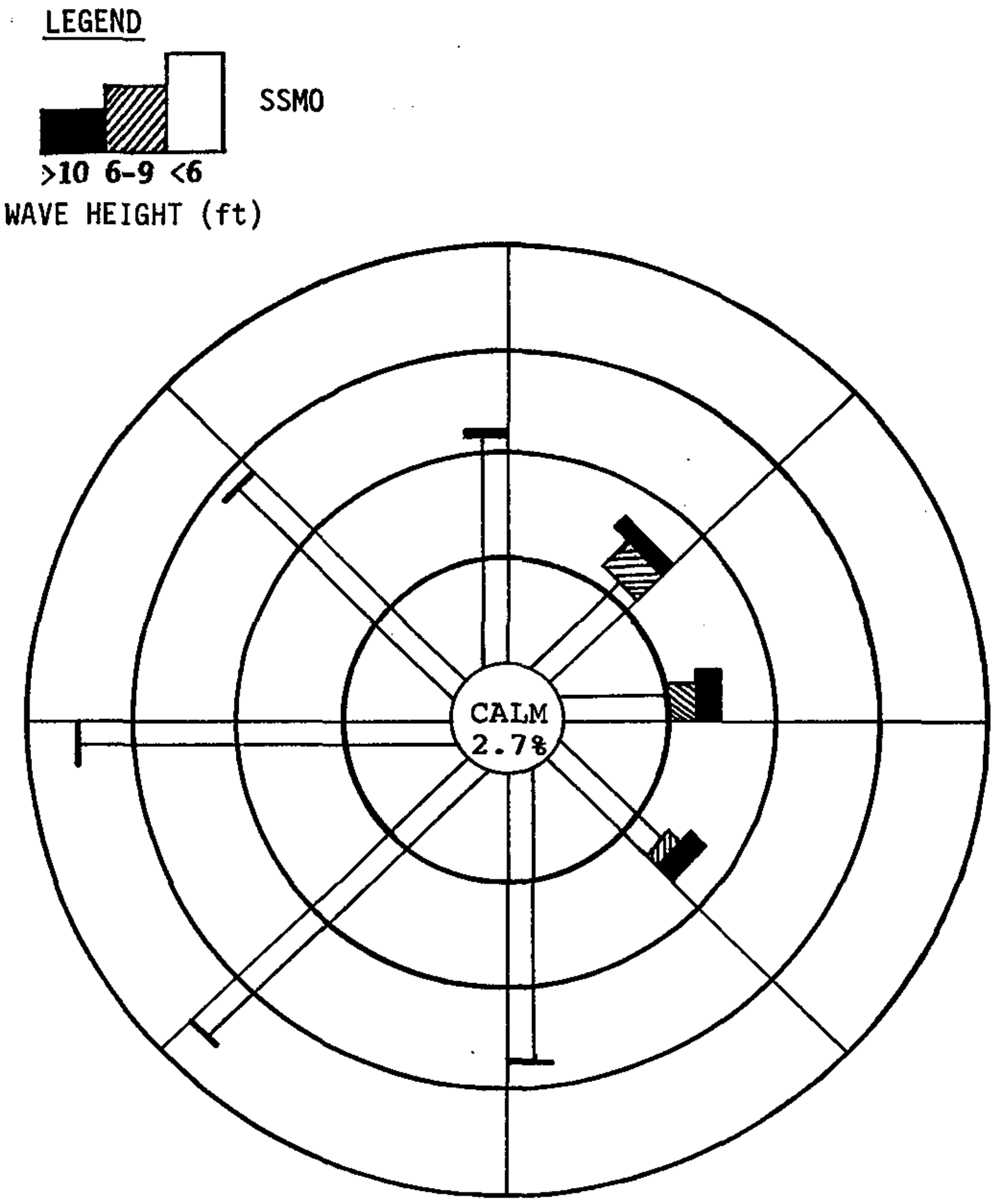


Figure I.1-3. Surface wave rose representative of Massachusetts Bay (from Raytheon Company, 1974).

Table I.1-4

Annual Occurrence Of Wave Height
Equalled Or Exceeded %

Direction	3.7 meters (12 Feet) SSMO Data	3.7 meters (12 Feet) USAF Data	3.0 meters (10 Feet) SSMO Data	3.0 meters (10 Feet) USAF Data	2.4 meters (8 Feet) SSMO Data	2.4 meters (8 Feet) USAF Data	1.8 meters (6 Feet) SSMO Data	1.8 meters (6 Feet) USAF Data
N	0.0	0.0	0.0	0.0	0.001	0.0	0.009	0.0
NE	0.176	0.180	0.355	0.364	0.709	0.727	1.673	1.716
E	0.334	0.423	0.490	0.621	0.723	0.917	1.669	2.117
SE	0.032	0.034	0.078	0.082	0.149	0.115	0.706	0.735
S	0.008	0.0	0.035	0.0	0.142	0.003	0.49	0.026
SW	0.002	0.0	0.01	0.0	0.05	0.0	0.30	0.011
W	0.001	0.0	0.005	0.0	0.027	0.0	0.167	0.003
NW	0.0	0.0	0.0	0.0	0.03	0.0	0.026	0.0
All Directions	0.553	0.637	0.973	1.067	1.831	1.762	5.04	4.608

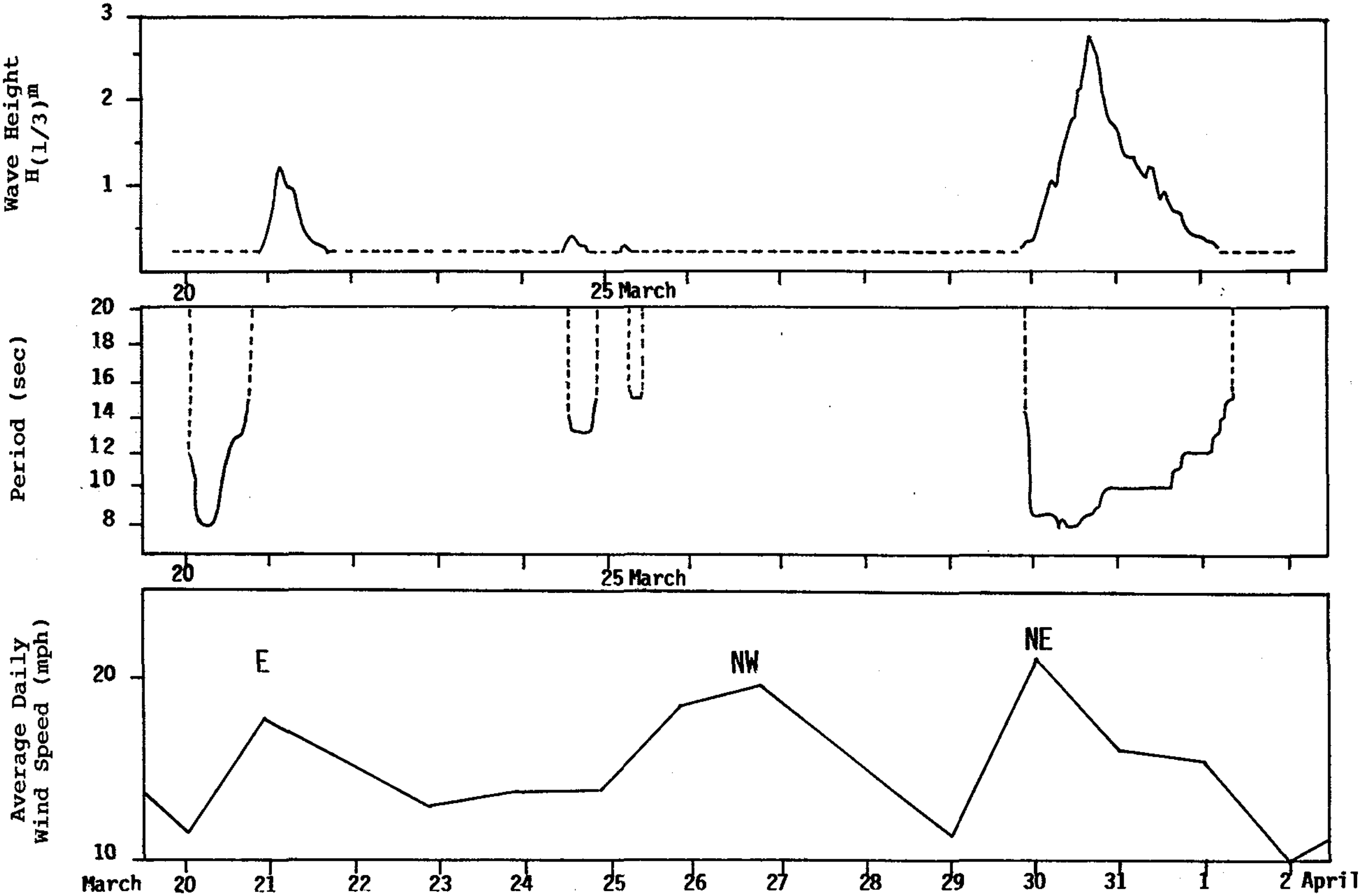


Figure I.1-4. Wave height and period measured in Massachusetts Bay (42°26'N,70°43'W). March 20-April 3, 1974 (Raytheon Company, 1974)

Because the FADS location is in water depths of 90 meters, only those waves with periods in excess of 12 seconds can directly influence the near-bottom current flow with sufficient intensity to increase the potential for sediment resuspension. It is apparent that such conditions did exist during the easterly wind events measured by Raytheon (Figure I.1-4) and that they can occur either as local, easterly wind generated waves or as ocean swell.

Review of the pressure data used by the DAISY instrumentation to measure wave motion during the July 1985 deployment indicated that no significant surface waves occurred during the deployment period. This is consistent with the expected meteorological conditions prevailing during that period, which would suggest a predominance of southwesterly winds.

I.2 Oceanography

The Foul Area Disposal Site is located in the northeast portion of Massachusetts Bay which is considered a western extension of the Gulf of Maine. The oceanography of the area is controlled by three major factors: the climate, as discussed above; the lack of significant river drainage into the bay; and the circulation of the Gulf of Maine. The latter is modified to a large extent by the presence of Stellwagen Bank on the eastern margin of the Bay which blocks the exchange of water at depth with the Gulf and the shelf beyond.

I.2.1 Water Masses, Temperature and Salinity

The temperature/salinity cycle of Massachusetts Bay is characterized by seasonal variability, with maximum temperatures occurring in a stratified water column during August and September and minimum temperatures occurring in an essentially isothermal water column in January and February. Bumpus (1974) presents annual temperature and salinity profiles from the vicinity of the Boston Lightship (Figure I.2-1) approximately 10 NM southwest of FADS which demonstrate the structure of the temperature/salinity changes, although absolute values may be slightly different. These are presented as Figures I.2-2 and I.2-3. The validity of these data as they apply to FADS is demonstrated through cross sections obtained over the northeast quadrant of Massachusetts Bay as shown in Figures I.2-1 and I.2-4.

These data indicate a minimum temperature in an isothermal water column of approximately 5°C occurring during the winter months and an extreme high temperature approaching 17-18°C in a highly stratified column during the late summer. The thermocline occurs at a depth of approximately 15 meters with the sharpest thermal gradient ranging from 15 to 10°C over a 5 meter depth interval to 20 meters. Below 20 meters, the water cools gradually to a nominal bottom temperature of 8° or 9°C. The stratification breaks down through vertical mixing during October

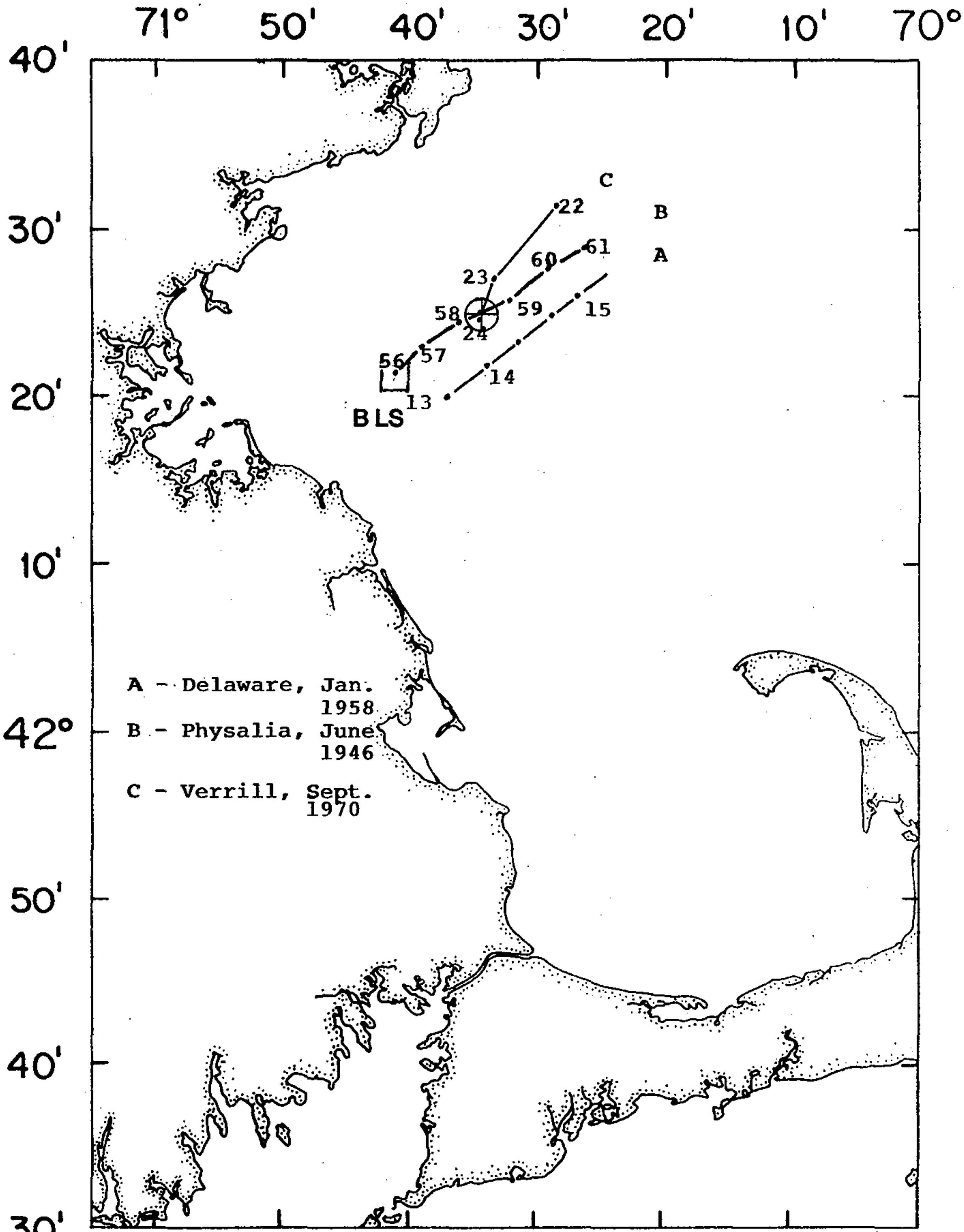


Figure I.2-1. Location of temperature transects in the vicinity of FADS. (Bumpus, 1974)

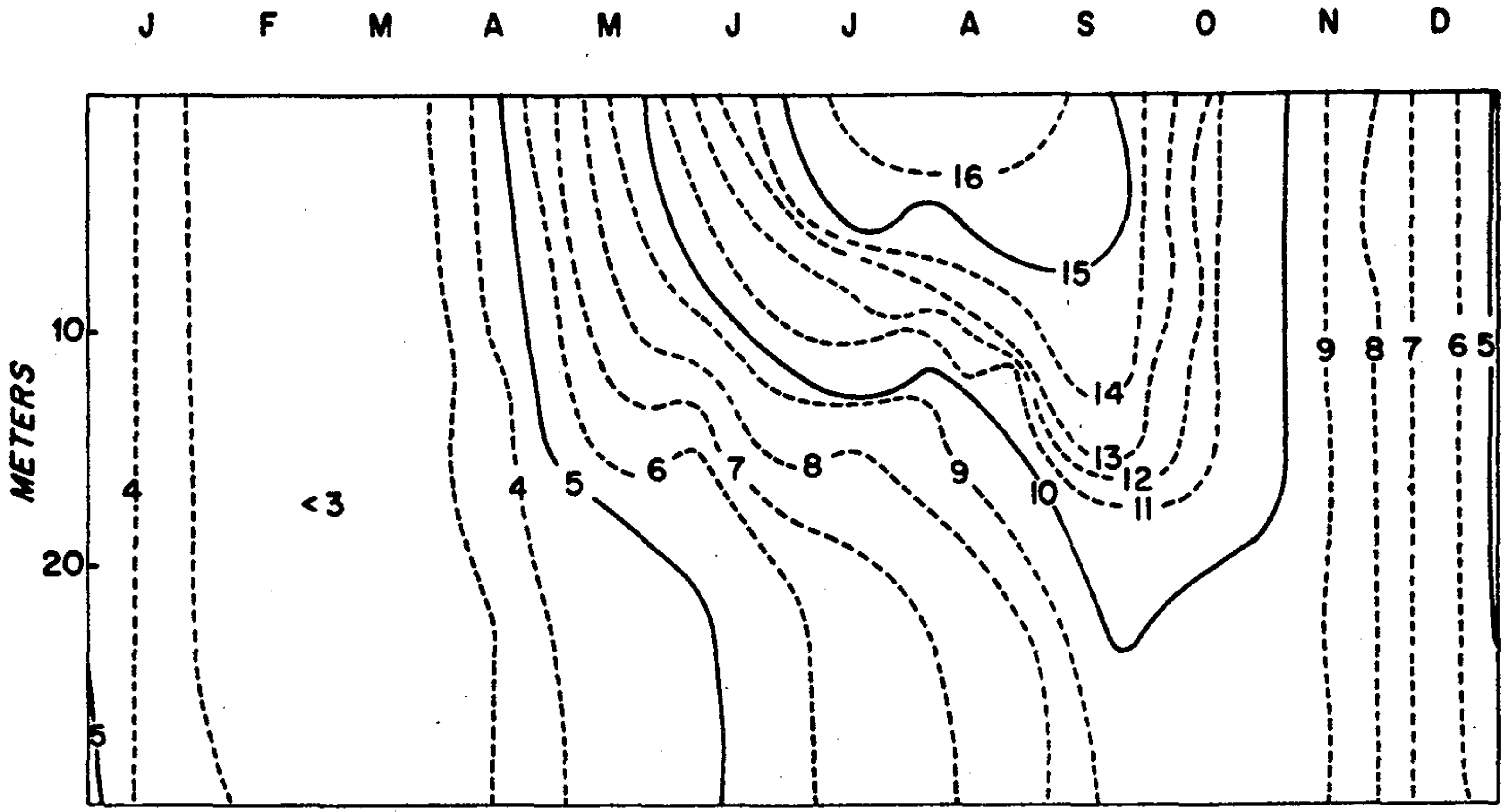


Figure I.2-2. Profile of mean annual temperature cycle at Boston Lightship, 1956-1970. (Bumpus, 1974)

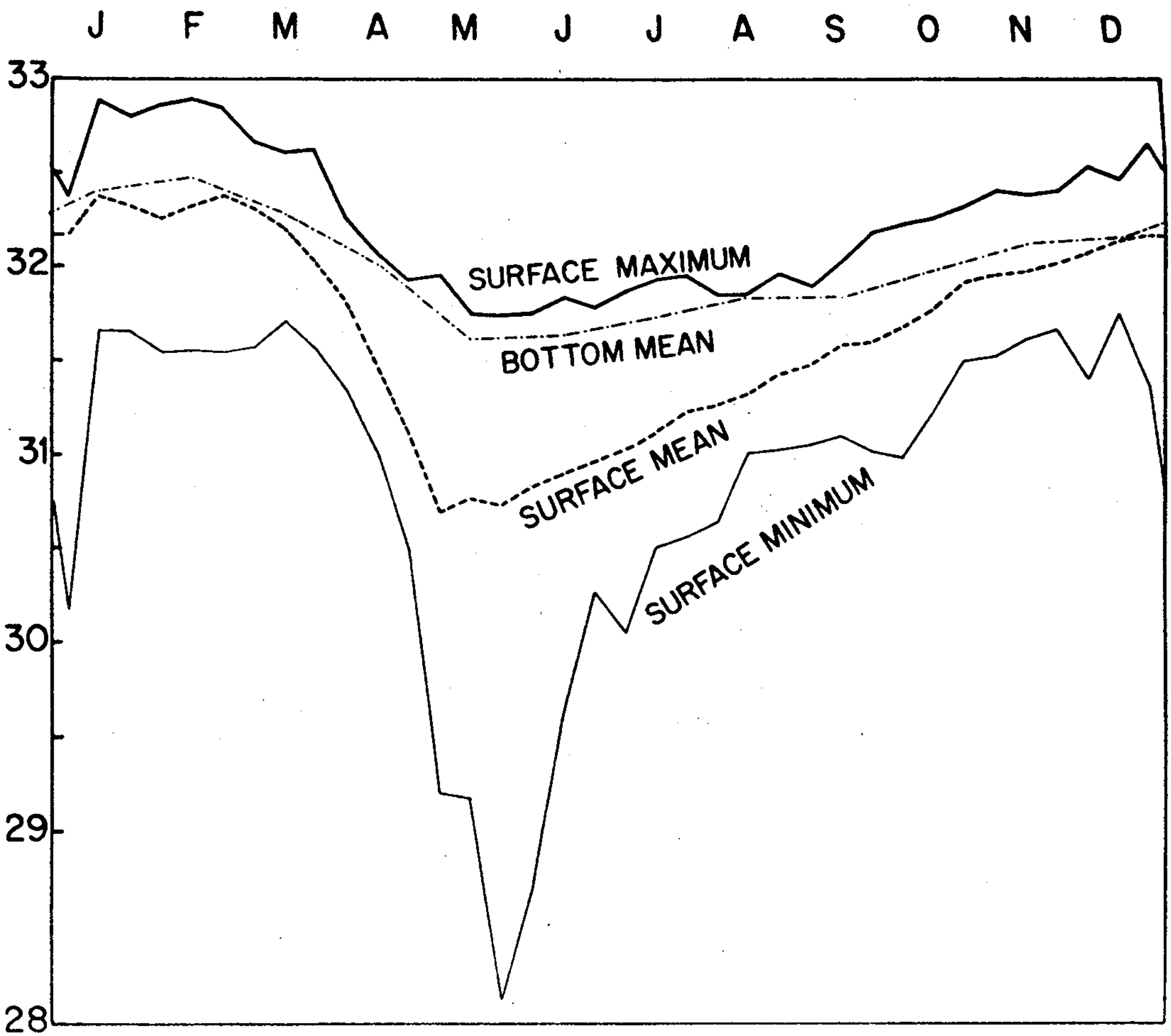


Figure I.2-3. Annual cycle of salinity at Boston Lightship, 1956-1970. (Bumpus, 1974)

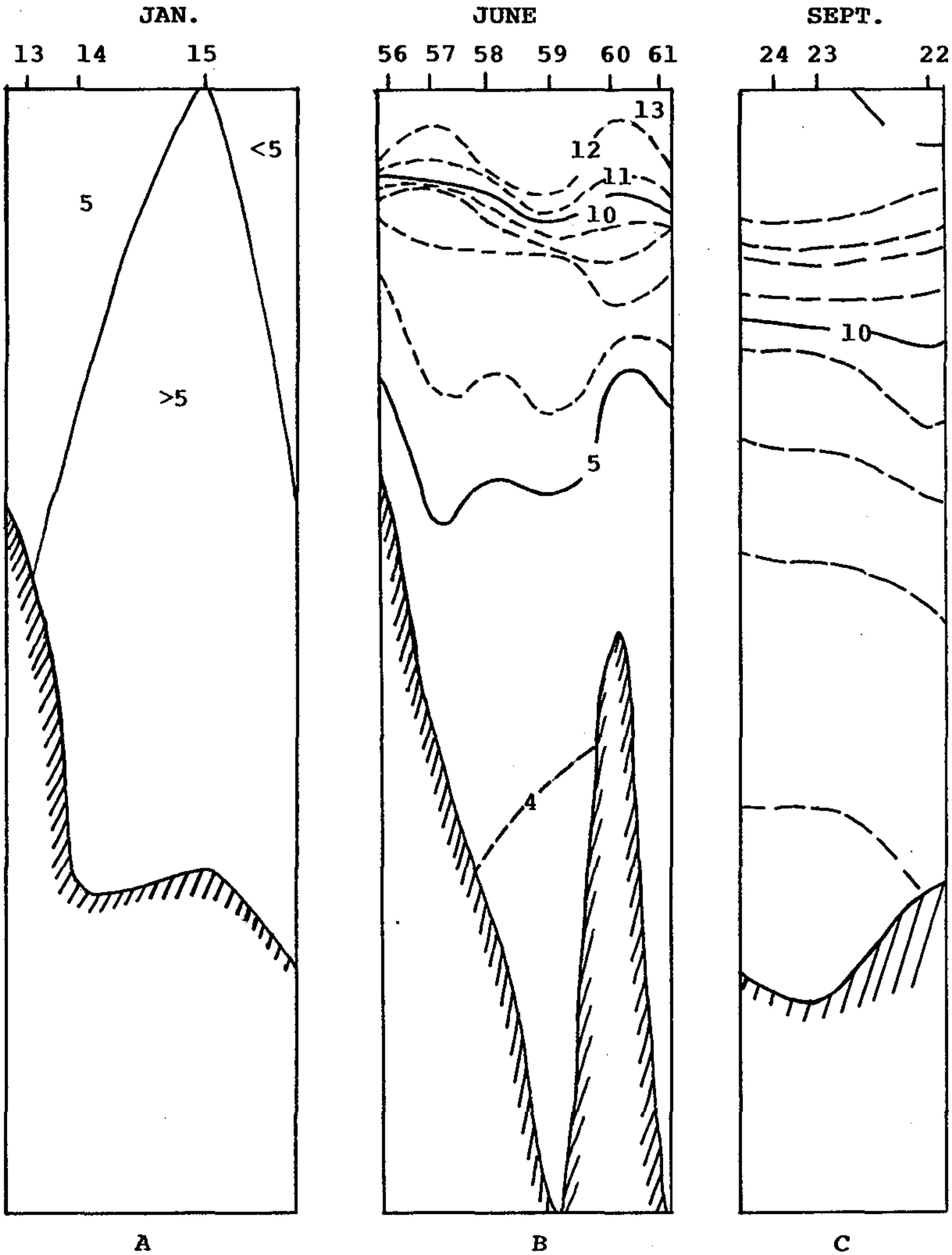


Figure I.2-4. Temperature transects in the vicinity of FADS. (Bumpus, 1974) and the water column is essentially isothermal from November until April.

The annual salinity cycle presented in Figure I.2-3 follows the expected pattern with minima in both the surface and bottom waters occurring in the late spring. As would be expected, the surface salinities are less than the bottom values and show a much greater range of fluctuation, particularly in the spring months when variations in the amount of runoff can have a significant effect. Surface salinities expected at FADS would have a maximum ranging between 32 and 33^{o}/oo during the winter months and minimums on the order of 31^{o}/oo during the spring. The bottom water is much more consistent, varying slightly around 32^{o}/oo. Bigelow (1927) was the first to document the seasonal cycle of salinity in Massachusetts Bay and Butman (1977) described in detail the changes in water column parameters in the middle of Massachusetts Bay (42°20'N, 70°35'W) occurring during the spring runoff of 1973. Figures I.2-5 and I.2-6 indicate vertical profiles of temperature and salinity occurring between March and June of that year. The change from a well mixed water column in March and April to the start of a stratified system with a developing thermocline at 15-20 meters is clearly seen in these figures. The reliability of these data in terms of conditions at FADS is demonstrated in Figures I.2-7, I.2-8 and I.2-9, which show the distribution of surface salinity on a seasonal basis (Bumpus, 1974). From these charts it is apparent that the salinity gradient parallels the coastline and, as expected, the surface salinities vary from a minimum of 30^{o}/oo in May to 32^{o}/oo during the winter months.

Prior to this program, the most site specific data obtained at FADS were collected by Gilbert (1975) at six stations distributed throughout the original "Massachusetts Bay Foul Area". The results of his study, taken during December 1973 and April, July, and October 1974, are presented in Table I.2-1. These data agree quite closely with the Bumpus (1974) data for the Boston Lightship except that they are higher in both temperature and salinity during the summer months. Surface temperatures of more than 20°C may reflect a small temporal variation in the upper water column during the sampling period and are not abnormally high values. The salinity of 34^{o}/oo however, is higher than expected from previous work.

Temperature and salinity data obtained with the Neil Brown DRCM during this program are presented in the Appendix and appear consistent with the expected results. During June a small mixed layer was present to a depth of approximately 10 meters at 12°C. The thermocline was beginning to form as a broad temperature gradient between 10 and 50 meters with a minimum temperature of 6°C. Below 5 meters, the temperature gradually decreased to a minimum of 5°C. During July, August and September, the absolute values of the temperature data are correct; however, the gradients appear to be smoothed as a result of the instrument being lowered faster than the response time of

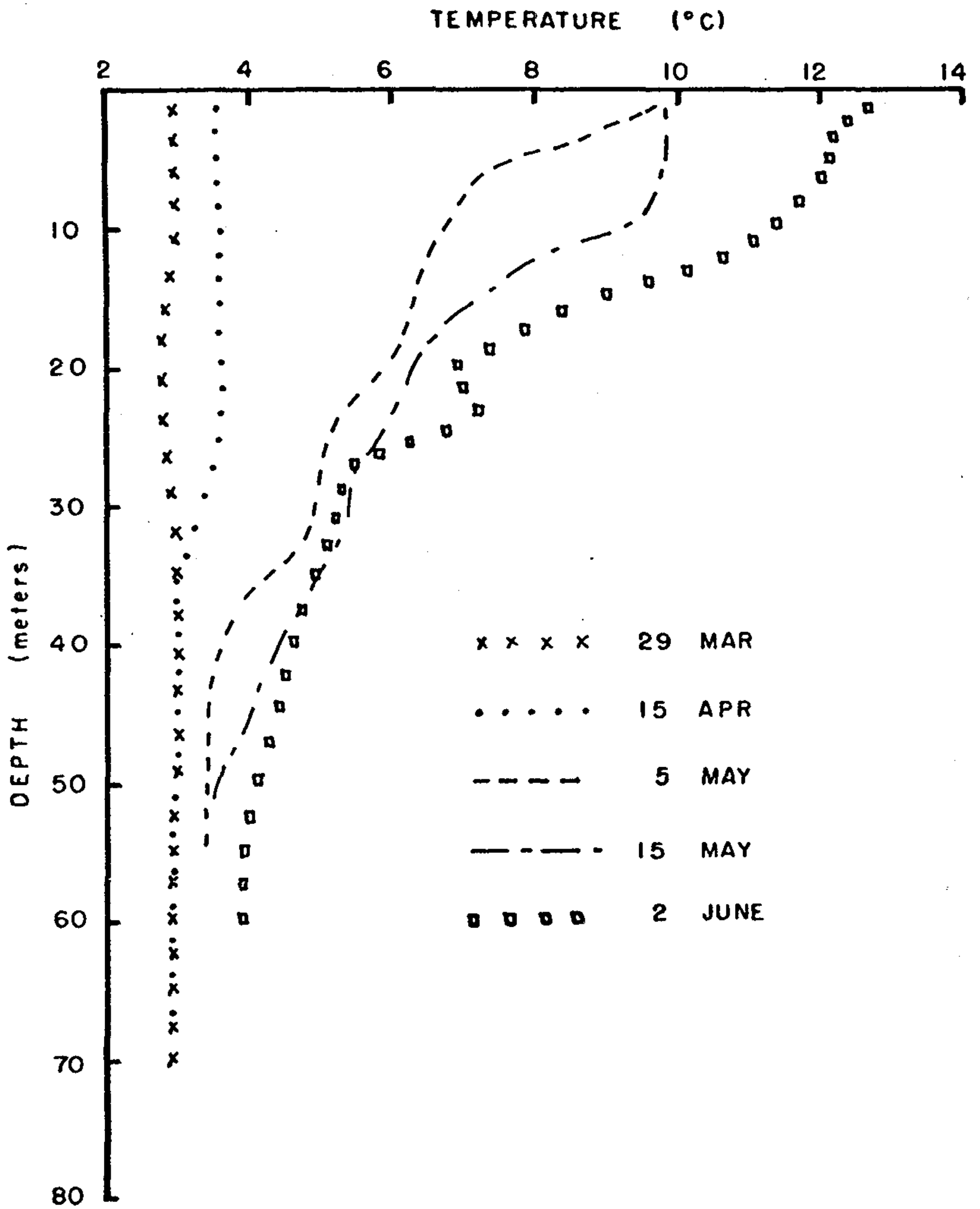


Figure I.2-5. Vertical profiles of temperature-March to June, 1973. (From Butman, 1977)

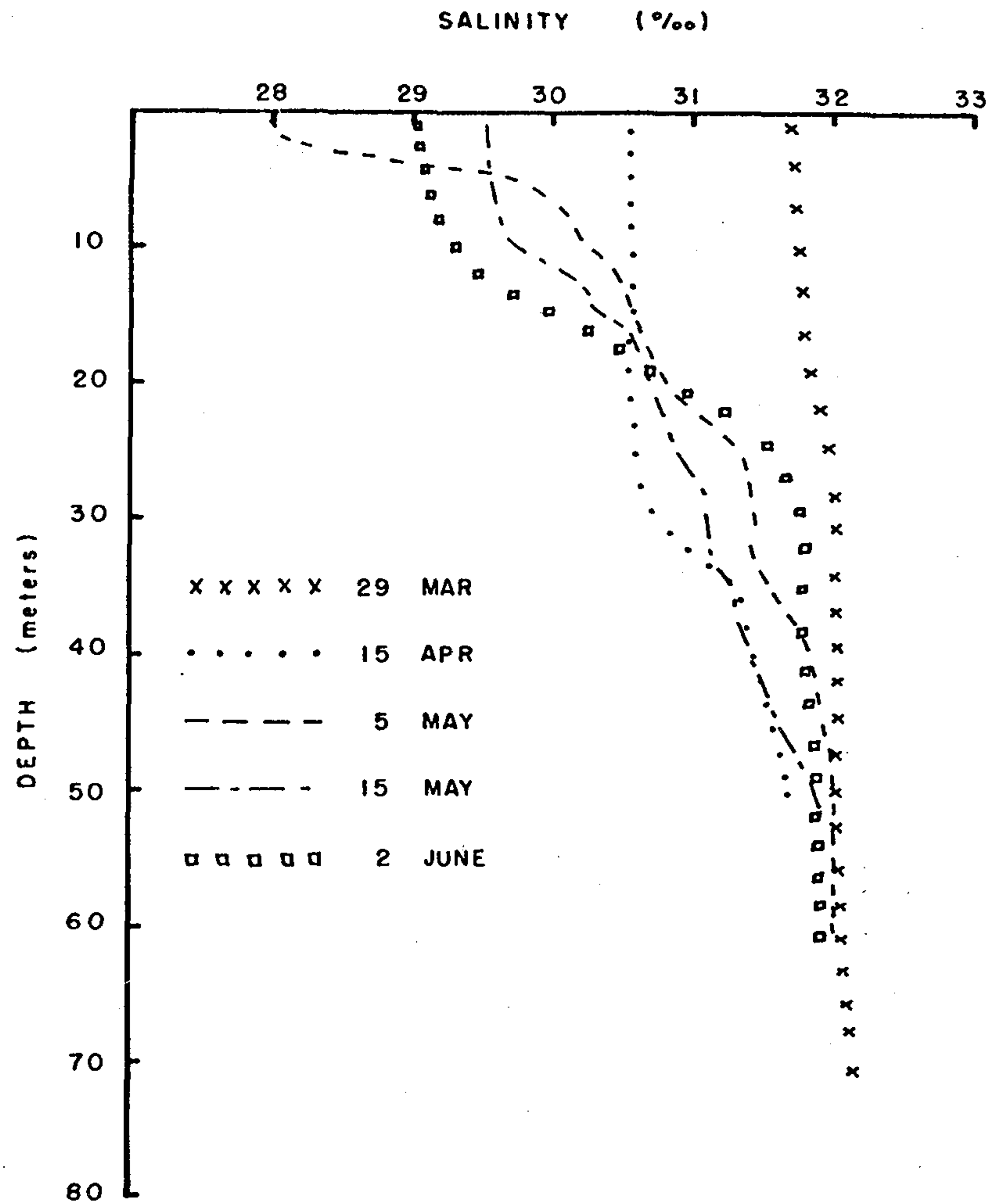


Figure I.2-6. Vertical profiles of salinity-March to June, 1973. (From Butman, 1977)

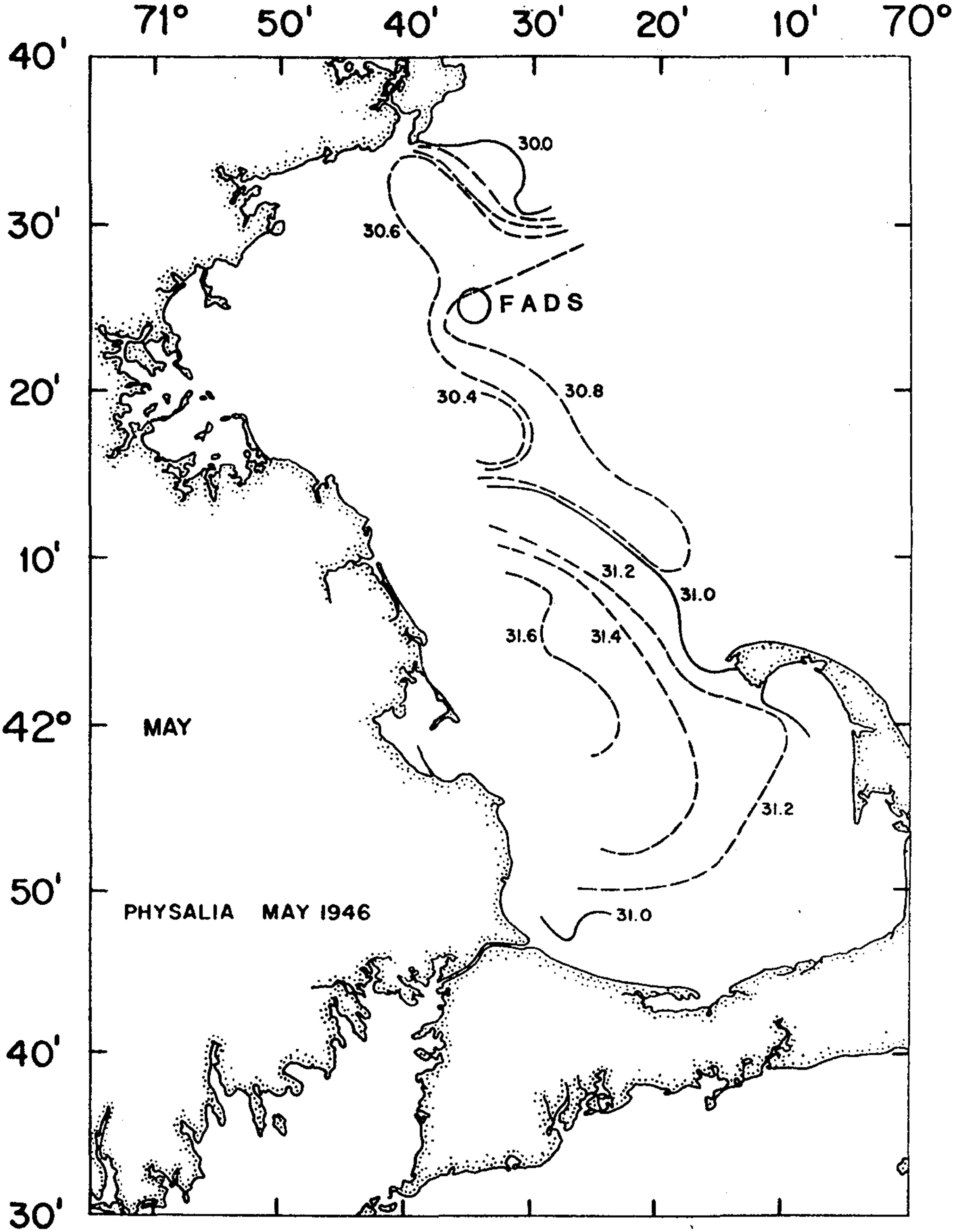


Figure I.2-7. Surface salinity in May, 1946. (Bumpus, 1974)

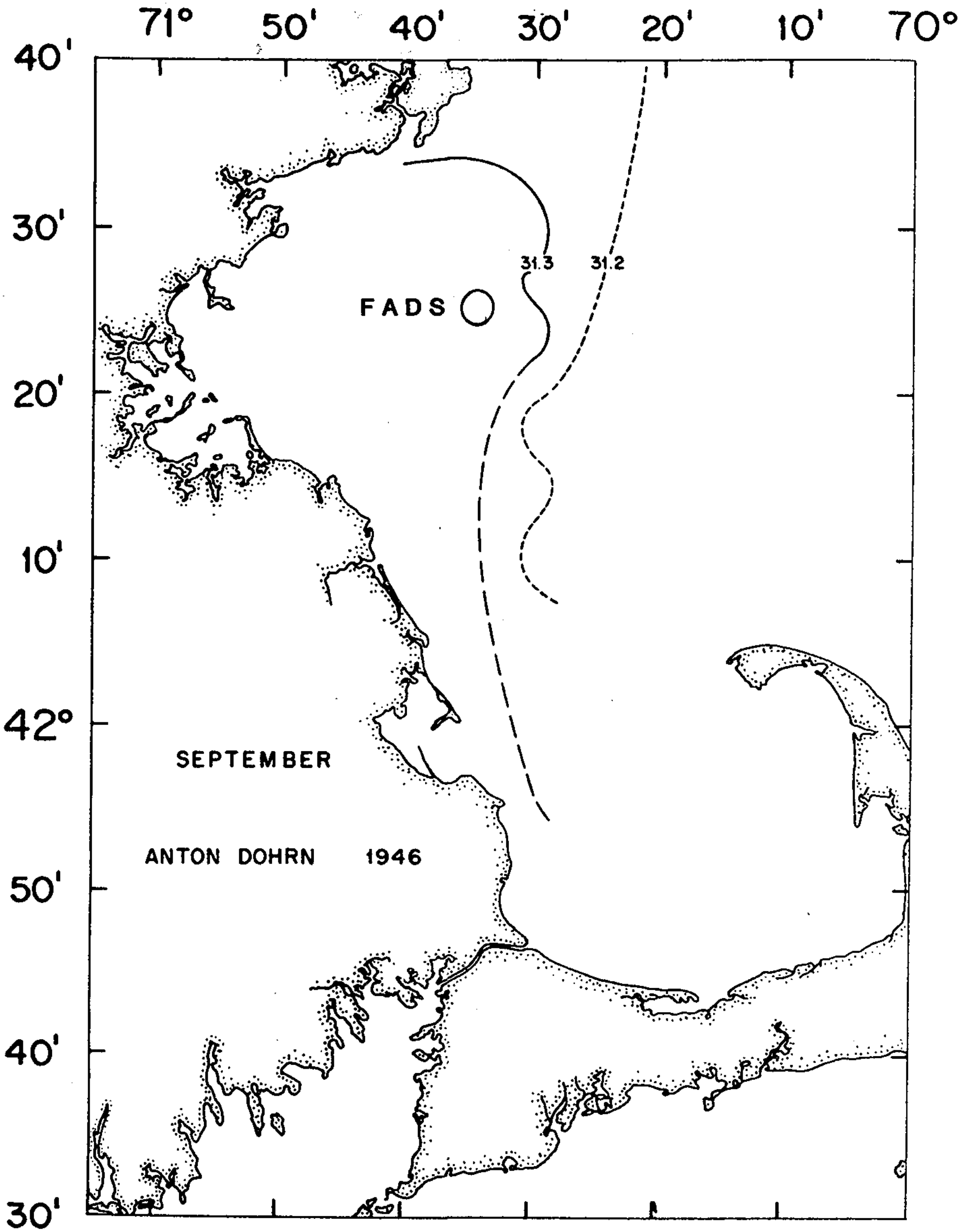


Figure I.2-8. Surface salinity in September, 1946. (Bumpus, 1974)

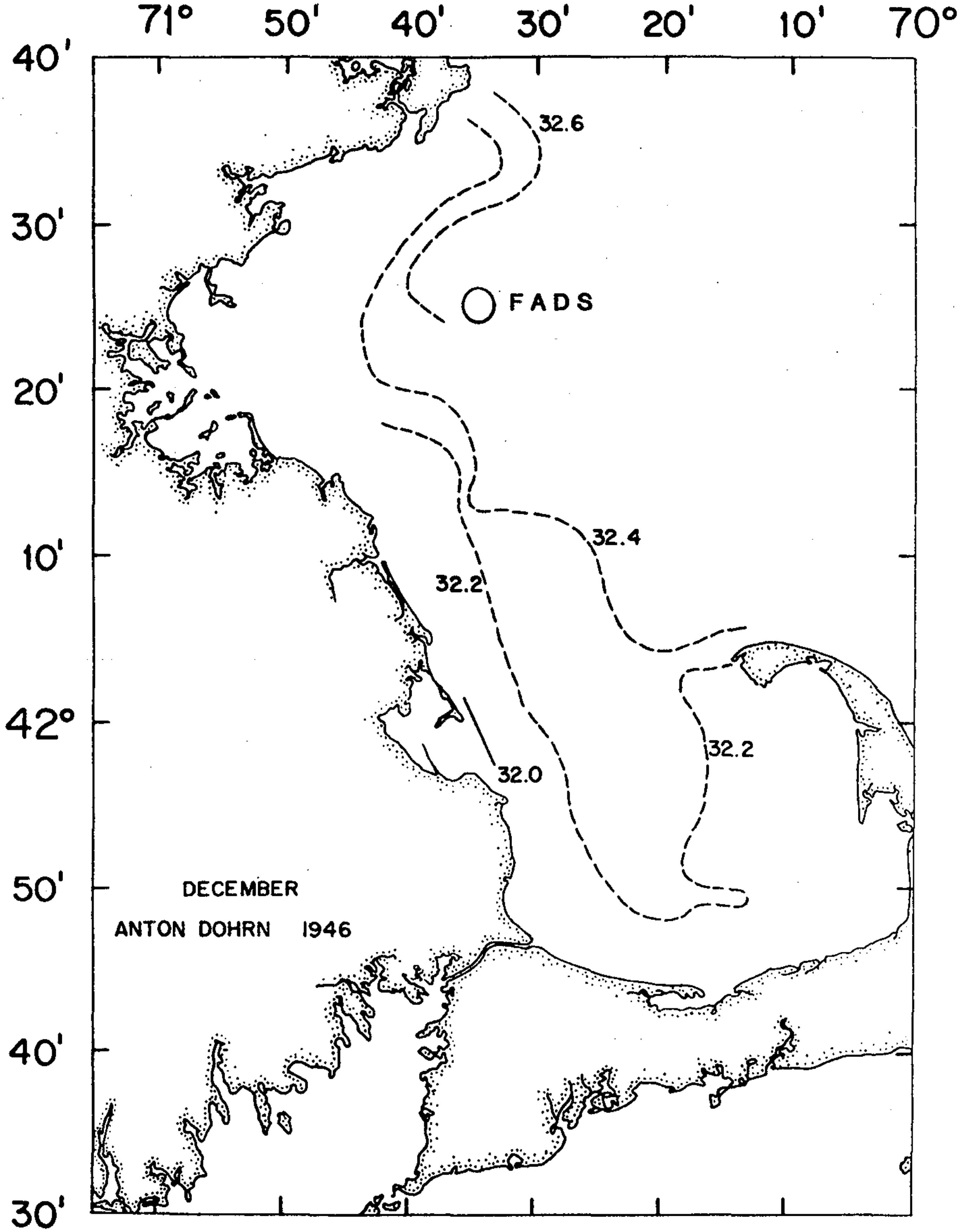


Figure I.2-9. Surface salinity in mid-December, 1946. (Bumpus, 1974)

Table I.2-1
Temperature And Salinity Data Obtained At The "Massachusetts Bay Foul Area" (Gilbert, 1975)

Station #	December 1973		April 1974		July 1974		October 1974	
Depth (m)	T°C	S ‰	T°C	S ‰	T°C	S ‰	T°C	S ‰
1-S	6.3	31.5	5.0	31.5	20.0	33.0	11.4	32.0
1-30	6.3	32.0	4.6	31.5	10.4	33.0	9.7	32.0
1-60	6.9	32.5	4.7	32.5	9.2	33.5	8.7	32.0
1-80	7.3	32.5	4.6	32.0	7.1	34.5	9.2	32.0
2-S	6.8	31.5	5.1	32.0	20.5	33.0	11.6	31.5
2-30	6.8	33.5	4.4	31.5	9.4	35.0	10.6	32.0
2-60	6.9	32.0	4.5	31.5	8.2	34.0	8.2	32.0
2-80	7.3	32.0	4.7	32.0	6.7	34.0	8.5	32.0
3-S	7.1	32.0	4.6	31.5	21.5	33.5	11.4	33.0
3-30	6.7	32.0	4.6	31.0	8.9	34.0	11.2	32.0
3-60	7.6	32.5	4.7	31.0	8.1	34.0	8.5	33.5
3-80	7.6	32.5	4.7	32.0	6.4	34.0	8.3	33.0
4-S	7.1	31.8	5.8	32.5	20.8	32.5	11.3	32.5
4-30	7.1	32.2	4.4	33.5	10.3	34.0	10.9	33.0
4-60	7.8	32.0	4.2	34.0	7.3	34.0	8.5	32.0
4-80	7.6	32.0	4.5	33.5	6.5	35.0	8.4	32.5
5-S	7.0	32.5	6.1	31.5	21.5	34.5	11.2	31.5
5-30	7.0	32.5	4.6	34.5	13.6	34.0	10.7	32.0
5-60	7.1	32.5	4.7	34.5	8.2	36.0	8.8	33.0
5-80	7.6	33.0	4.6	31.5	6.4	34.5	9.1	32.0
6-S	7.3	31.8	6.4	32.0	20.9	34.5	11.2	32.0
6-30	7.1	33.0	4.5	32.5	10.0	35.0	11.1	32.0
6-60	7.6	32.0	4.2	31.5	8.8	34.5	8.3	32.5
6-80	7.5	32.0	4.6	32.0	7.2	35.5	8.2	32.0
Mean								
-S	6.9	31.8	5.5	31.8	20.8	33.5	11.3	32.1
30	6.8	32.5	4.5	32.4	10.4	34.1	10.7	32.1
60	7.3	32.2	4.5	32.5	8.3	34.3	8.5	32.5
80	7.5	32.3	4.6	32.1	6.7	34.5	8.6	32.2
Total	7.1	32.2	4.7	32.2	11.5	34.1	9.7	32.2

the thermistor. The surface temperature in July had warmed to 14.5°C and reached a maximum of 17°C during August and September. Throughout the period the bottom water remained at 6°C. Evidence that the thermistor was lowered too fast is shown by the October profile, which displays a pronounced mixed layer to a depth of 25 meters with a constant temperature of 14°C. Below the mixed layer a sharp thermal gradient can be seen to the maximum depth attained at 50 meters. This cast was taken on a day with strong northwest winds which would have increased the mixing of the upper water column. Finally, during the winter months, the water column was essentially isothermal with the temperature of approximately 5°C.

Additional evidence of the stratified thermal structure occurring at FADS is shown by the temperature data obtained from the four current meters deployed at the site during September and October as shown in Figure I.2-10. From surface to bottom there is a decrease in both the absolute temperature and the variability of the record. The temperature decreases by approximately 10°C from 17°C at the surface. The greatest variability in temperature occurs at the 35 meter depth, where small oscillations induced by tidal forces cause large variability in the temperature record (up to 2°C). Because this meter is located in the thermocline, the large temperature gradient results in this characteristic signature. Below the thermocline the variability of the temperature is much less.

An important observation in this record is the impact of Hurricane Gloria which occurred on 27 and 28 September (days 270 and 271). The passage of this storm resulted in a decrease of surface temperature and marked increase in subsurface temperatures for a short period of time. This phenomenon is most likely a combination of turbulent mixing near the surface and transport of warmer water into the subsurface layers. The fact that all records returned to essentially pre-storm conditions indicates that no major overturn of the water column occurred as a result of this event.

The only temperature record obtained from the winter deployment at FADS (Figure I.2-11) indicates a bottom temperature of approximately 4°C with no major variability throughout the record. Again, this is consistent with the expected values as discussed above.

The salinity measurements obtained during this study also support the expected distribution and tend to support the observations of Gilbert (1975). During September and October the salinity increased with depth ranging from 31.5 to 32.5^{o}/oo, while during the winter months the data are essentially constant with depth at 33^{o}/oo; these are slightly higher than the values observed by Bumpus (1974), but consistent with those of Gilbert (1975).

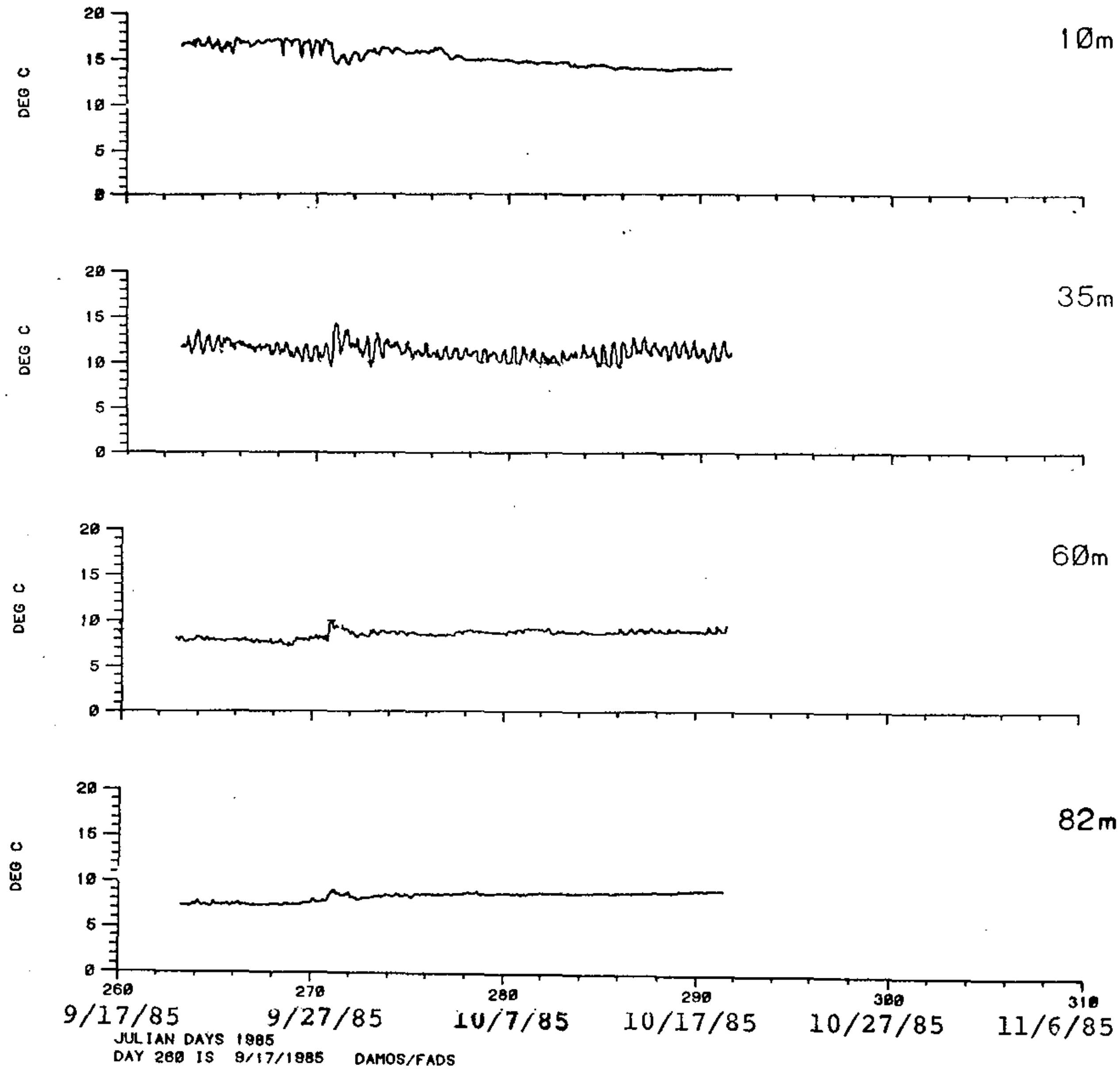


Figure I.2-10. Time series of raw temperature data obtained at four depths at FADS during the period of Sept. 20 to Oct. 18, 1985.

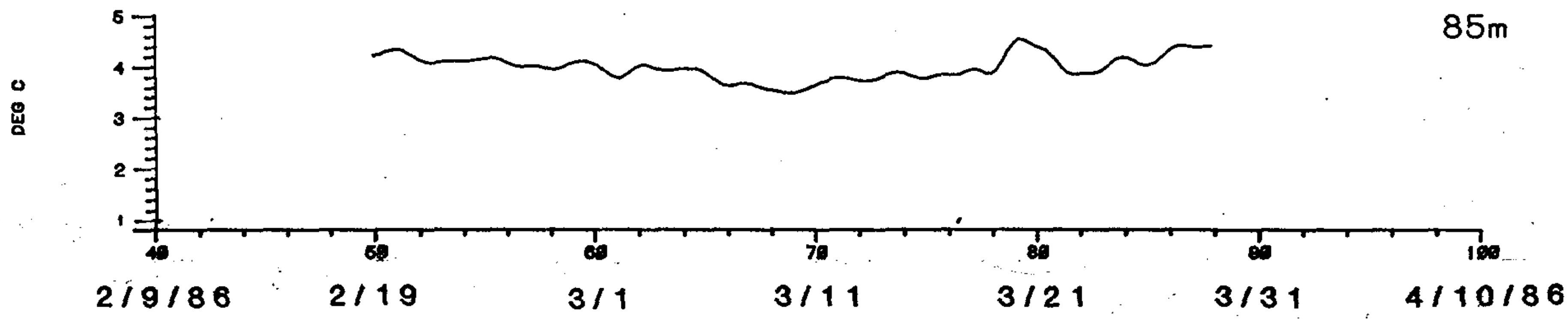


Figure I.2-11. Seawater temperature at 85m from FADS winter 1986 current meter deployment.

In summary, the water column at FADS behaves in a manner typical of northeastern continental shelf regions, with isothermal conditions of approximately 5°C during the winter, giving way to stratified conditions with maximum surface temperatures on the order of 18°C, and a strong thermocline at 20 meters during the summer months. The water column overturns during the late fall, returning to isothermal conditions. Salinity minima occur in late spring as a result of increased runoff, but vary only a few parts per thousand with most values ranging from 31 to 33°/oo.

I.2.2 Circulation: Currents, Waves

Water circulation in Massachusetts Bay is strongly influenced by the counterclockwise flow, or gyre, displayed by the Gulf of Maine (Figure I.2-12) (Bigelow, 1927; Sutcliffe et al., 1976; Brown & Beardsley, 1978; Harris, 1972). Strong localized atidal currents (mean tidal range 2-3 meters) and wind driven currents complicate the normal counterclockwise water movements (Bumpus, 1974; Parker and Pearce, 1973; Padan, 1977). Studies of circulation in Massachusetts Bay (Butman, 1977) have demonstrated the following key features:

- current speeds are primarily a function of semi-diurnal rotary tides,
- currents can be dominated by wind stress, particularly in winter,
- density distributions established during spring runoff can also alter the normal current field.

On a large scale, circulation within Massachusetts Bay is one component of the overall Gulf of Maine system (Figure I.2-12). The circulation of the Gulf consists of two circular gyres, one counterclockwise within the interior of the Gulf, and the second, clockwise over Georges Bank. Massachusetts Bay waters are included as the western portion of the counterclockwise gyre within the Gulf. Previous studies using drift bottles and sea-bed drifters (Bigelow, 1927; Bumpus, 1976) indicated seasonal variability in this circulation under the combined effects of local wind stress and input of freshwater inflows. In general, the circulation gyres are most strongly developed in the summer; during the winter, the interior gyre tends to move northward and becomes more diffuse (Figure I.2-13).

Modeling efforts (Csanady, 1974) have suggested that the double gyre system can be predicted simply by the effects of surface wind stresses acting in combination with the bottom friction. Furthermore, the strength of the circulation field varies in response to the input of lower salinity waters and vertical mixing rates while the direction is largely dependent on wind direction.

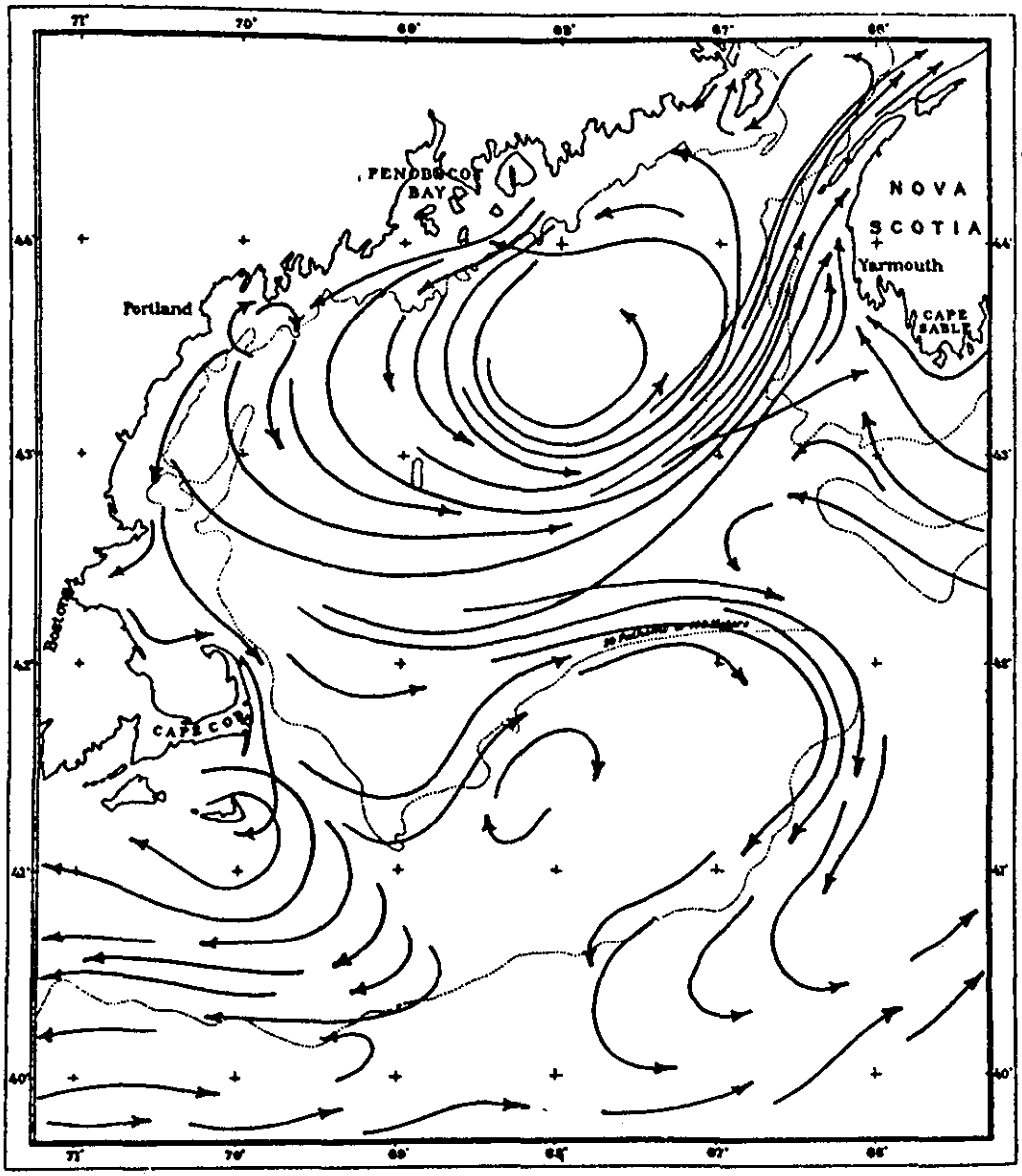


Figure I.2-12. The dominant circulation of surface waters of the Gulf of Maine in July and August (Bigelow, 1927).

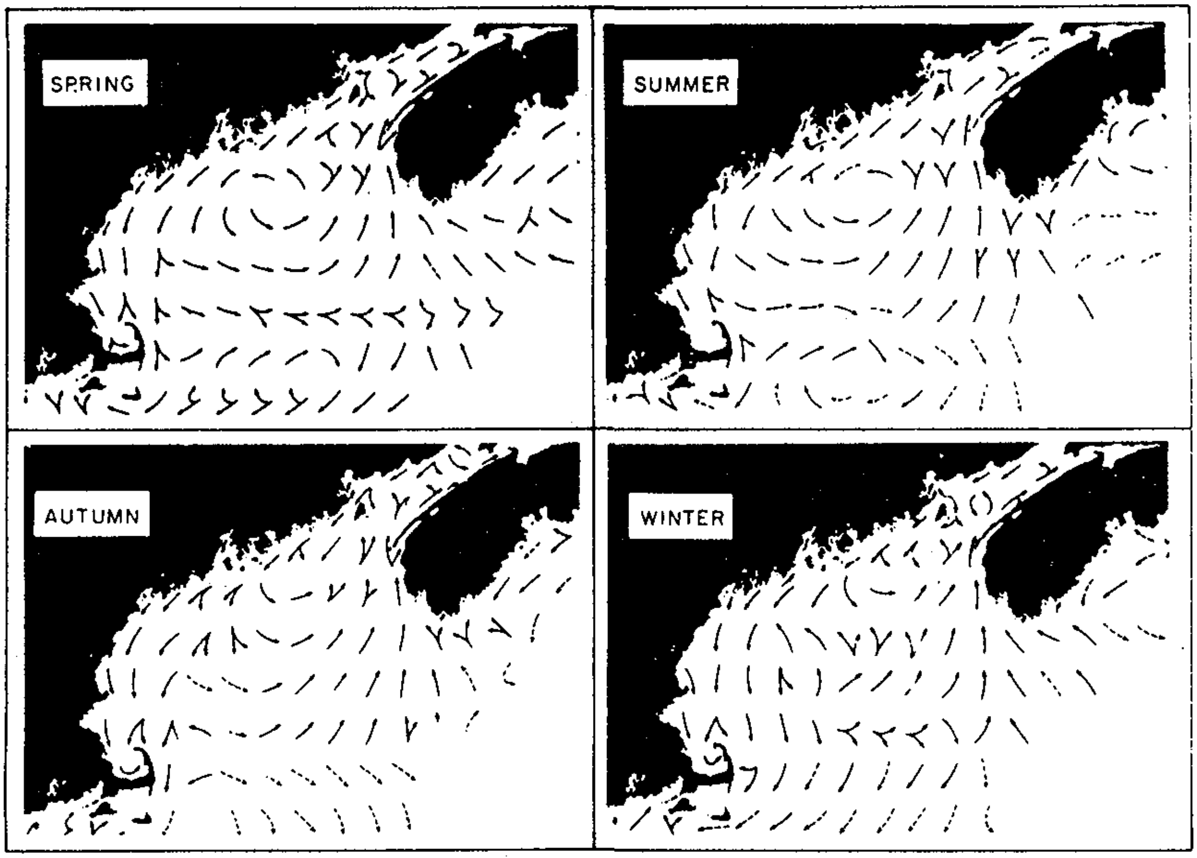


Figure I.2-13. The seasonal variations of circulation in the Gulf of Maine. The characteristic counterclockwise current is well-developed near the center of the Gulf in the spring. As the year progresses, the center of the gyre tends to move northward as the driving forces weaken and the current becomes diffuse (Bumpus and Lauzier, 1965).

As a result of these regional circulation characteristics and the variability of the local meteorological regime, Massachusetts Bay can be expected to have a general counterclockwise circulation with a moderate degree of temporal and spatial variability. In the immediate vicinity of FADS the long term currents would be expected to be generally in a southerly direction. Drifters released near the crest of Stellwagen Bank were recovered along the eastern shore of Cape Cod, while those released on the western margin of the Bank were recovered in Cape Cod Bay (Schlee et al., 1973). In all cases the drift velocities were very low, ranging from 2 to 10 cm/sec.

Shorter time scale variability is dominated by the semi-diurnal component of the local tide field in which tidal currents are more developed and stronger within the shallow nearshore area. Riser and Jankowski (1974) noted that the general trend of tidal flow at the Boston Lightship Dumping Ground was southeasterly after high tide and northwesterly after low tide. These observations agree closely with those of Bumpus (1974) for the entire Massachusetts Bay including the FADS area.

The near-bottom circulation of the Massachusetts Bay varies primarily as a function of topography, with highest values observed over crest regions of topographic features such as Stellwagen Bank and lowest values observed in the depressions located in the central portion of the Bay. Observations by Schlee et al. (1973) indicated velocities on the crest approaching 40 cm/sec while those in the deeper basin areas remained below 20 cm/sec. These velocities suggest that winnowing of fine particles and/or erosion or coarser sediments can occur on the topographic features, but that deposition of fine materials would be expected in the basin areas.

Gilbert (1975) observed bottom currents within the FADS area that were extremely low (less than 10 cm/sec) but had greater velocities higher in the water column (Table I.2-2). Butman (1977) deployed a bottom current meter approximately 5 NM south of FADS and found similar conditions, with average speeds of approximately 5 cm/sec and maximum values less than 20 cm/sec 99% of the time but approaching 30 cm/sec under extreme conditions. Tidal components of these currents reached values of only 6 cm/sec oriented in an east-west direction. Current measurements made under the DAMOS program (NUSC, 1979) also indicated extremely low current velocities, generally less than 10 cm/sec (Figure I.2-14).

Butman (1977) deployed several bottom current meters for a one year period throughout Massachusetts Bay and was able to characterize the response of the bottom currents to meteorological events during the winter. During strong easterly storm events, the response of sea level and of bottom currents are related. The local sea surface setup is toward the west and is superimposed on absolute changes in the level of the Bay, controlled primarily by the response of the Gulf of Maine to the

Table I.2-2

Summary of Current Statistics for 1974
(Gilbert, 1975)

Location In Water Column	January	April	June	July August	September	October
Upper Mean Speed (cm/sec)	9	12	*	10	*	10
Middle Mean Speed (cm/sec)	8	*	9	6	*	7
Lower Mean Speed (cm/sec)	4	*	4	*	5	5
Upper Maximum Speed (cm/sec)	21	44	*	30	*	28
Middle Maximum Speed (cm/sec)	20	*	26	19	*	22
Lower Maximum speed (cm/sec)	15	*	17	*	15	17

*No data coverage

Upper = 15.2m
Middle = 61.0m
Lower = 84.2m

These values are all relative to Mean Low Water (MLW). (The upper current meter was moved to a depth of 30.5m after the initial deployment.)

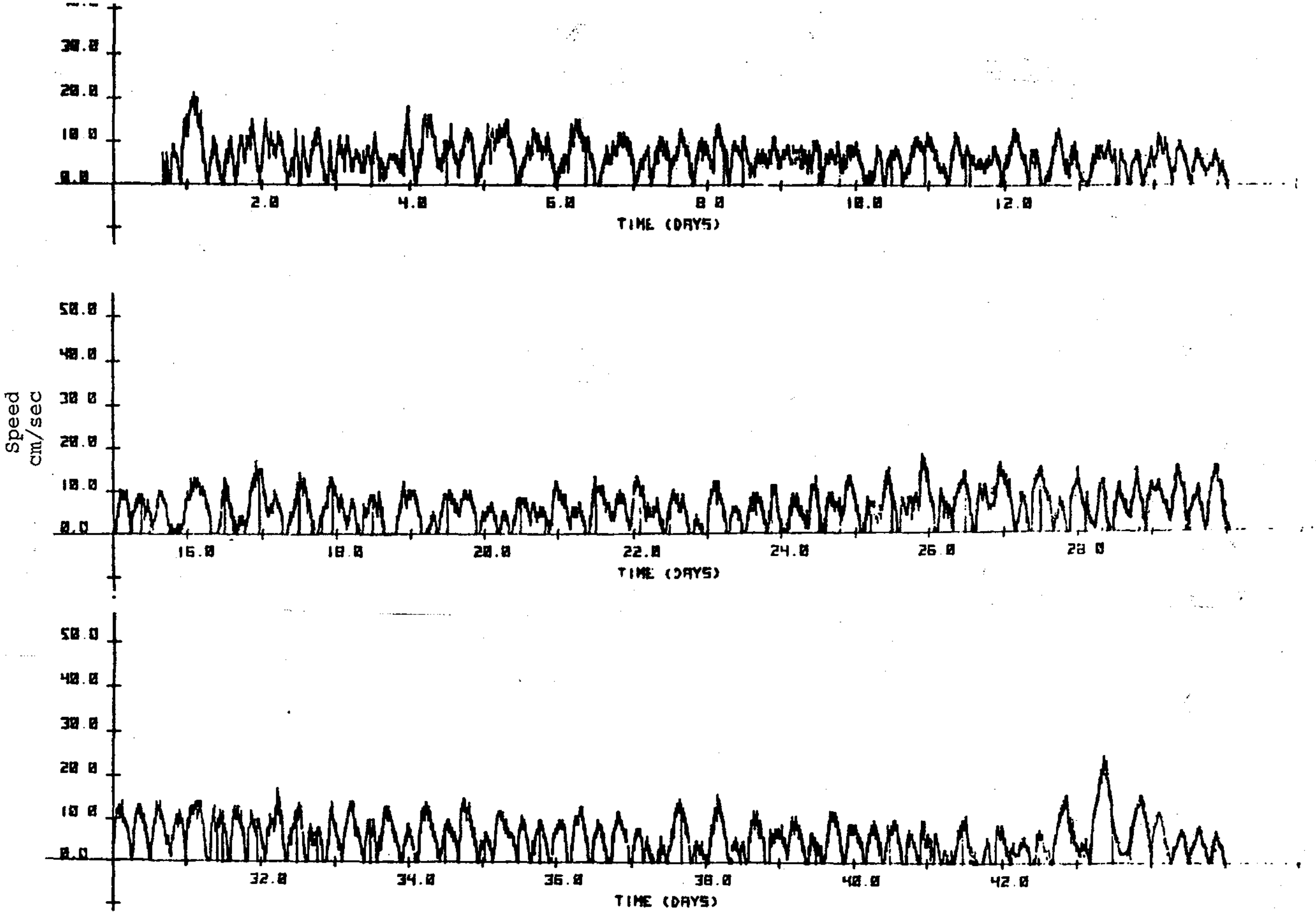


Figure I.2-14. Near-bottom current speed (cm/sec) at FADS from May 23, 1978 through July 10, 1978 (NUSC, 1979).

storm. Local sea surface set-up requires approximately one hour, while complete Bay-wide set-up requires 6-12 hours. During this sea surface set-up, the currents flow in the direction of the wind (westward) in shallow near-shore waters and opposite to the wind (eastward) in the deep basin areas. These bottom currents are affected somewhat by the topography of the Bay, in particular Stellwagen Bank, so that they generally flow more southeasterly in the vicinity of FADS. The wind-driven deep currents are established approximately 12 hours after the wind stress is applied and remain essentially constant for the duration of the storm.

Measured changes in sea level (Bohlen, 1981) associated with major storm events (see Table I.1-3) show local set-up of more than 2.5 meters can occur with extremely strong easterly winds. Figure I.2-15 presents a generalized view of the bottom current circulation associated with such easterly storms (Butman, 1977). Note that while flow on the crest of Stellwagen Bank is in the direction of the wind, the bottom currents in the basin near FADS are southeasterly with much lower velocity.

During other months of the year Butman (1977) found no relation between bottom currents and meteorological events;, however, during the spring months, the low frequency currents in the vicinity of FADS can flow to the northward, because they are on the western margin of a clockwise-flowing gyre surrounding a lens of lighter, fresher water introduced from the eastern side of the basin. This fresh water is not derived from local sources but from the discharge of the Merrimack River into the Gulf of Maine.

Butman (1977) also concluded that the sediments in Massachusetts Bay are in equilibrium with the bottom currents and that those currents are not sufficient to move material regularly in the deep basin areas. However, the occurrence of high energy easterly storms may create waves with sufficient amplitude and period to affect the bottom sediments; should any material be resuspended it can be expected to be transported in the southeasterly direction shown in Figure I.2-15. Review of historical data (Bohlen, 1981) indicates that such high energy events have a recurrence interval of approximately once every ten years.

Estimates of the effect of these storms can best be accomplished through analytical calculations of wave characteristics through procedures outlined in the U.S. Army, Corps of Engineers Shore Protection Manual (USACE, 1984). As discussed in previous sections, the wave regime in the vicinity of FADS is extremely fetch-limited in all directions except the easterly quadrant; therefore, calculations need only be applied to easterly storms. Under easterly storm conditions, the wave field will be duration-limited and seldom, if ever, will reach a fully developed state. A summary of predicted wave characteristics for the FADS region is presented in Table I.2-3.

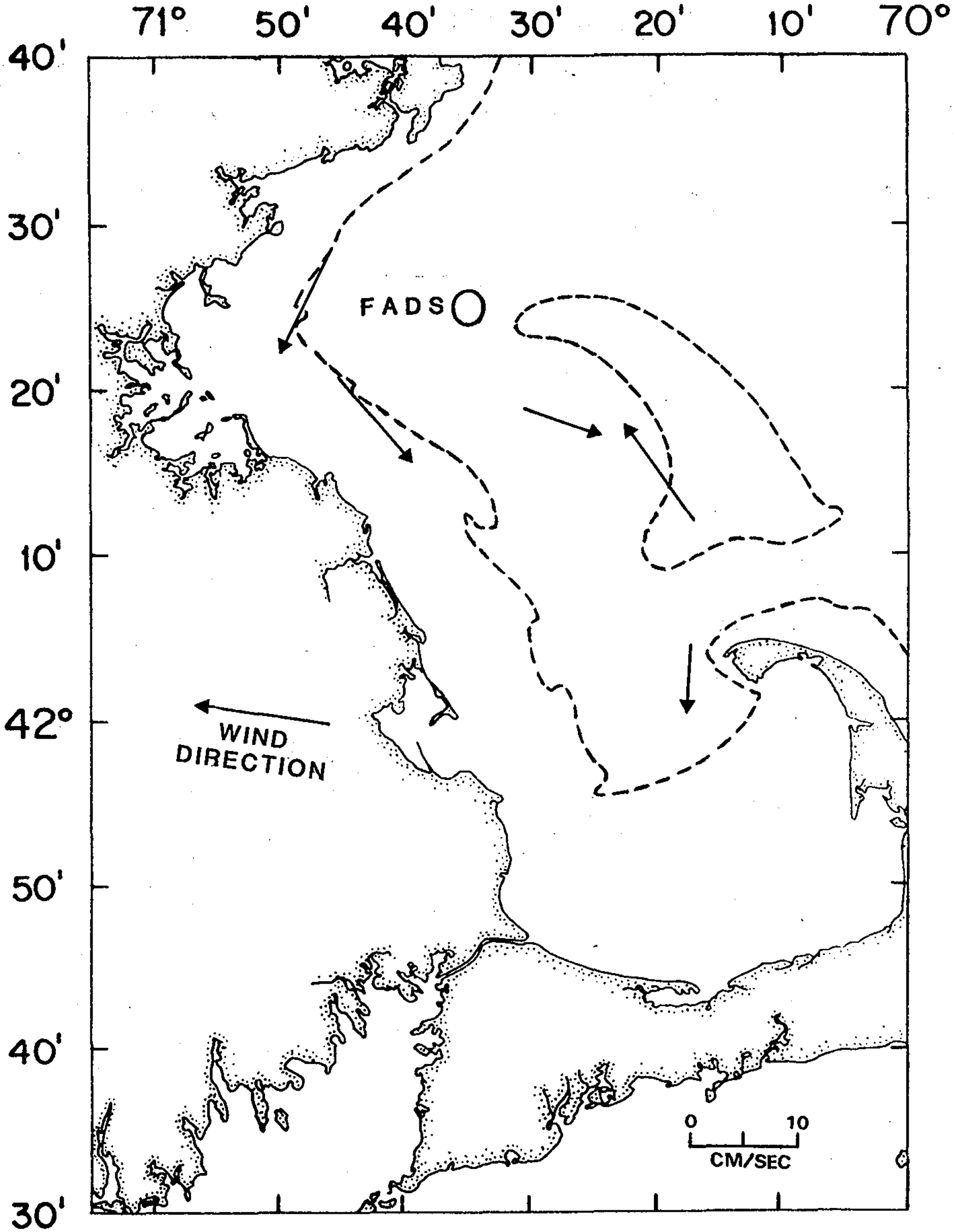


Figure I.2-15. Generalized response of bottom currents to wind constructed from measurements made at different times, but under similar wind conditions (Butman, 1977).

Table I.2-3

Predicted Deepwater Wave Characteristics
Duration Limited Conditions
(USACE, 1984)

Wind Speed mph	Wind Stress Factor mph	Significant Height in Feet (Period in Seconds)		
		Duration		
		3 hrs	6 hrs	12 hrs
37	50	6.5(5.5)	10.5(7.5)	18(11)
40	55	7(5.6)	12(8.0)	20(11.5)
43	60	8(6.0)	13(8.5)	22.5(12)
46	65	9(6.1)	15(8.7)	25(12.5)
49	70	9.5(6.5)	16(9.0)	27(12.7)
52	75	10.5(6.7)	17(9.5)	30(13.0)
55	80	11(6.8)	19(9.6)	32(13.5)
58	85	12(7.0)	20(10.0)	35(14.0)
61	90	13(7.25)	22(10.0)	37(14.5)
64	95	14(7.5)	23(10.5)	39(14.8)
67	100	15(7.5)	25(11.0)	42(15.0)

Because wave periods greater than 12 seconds are required to significantly interact with the bottom sediments in the water depths of 90 meters encountered at this site, it is apparent that only those storms with a duration greater than 12 hours have any potential influence on sediment transport.

In summary, previous data indicate that FADS can be expected to be a low energy region with potential for resuspension of dredged material only under extreme easterly storm conditions which occur infrequently during the winter months. If resuspension should occur under these conditions, transport would be in a southeasterly direction into the deep basin in the center of Massachusetts Bay.

In order to verify these expected conditions, current meter and suspended sediment measurements were attempted during three deployment periods using the instrumentation and procedures described in Section I.A of Report No. SAIC-85/7528&93. The three measurement periods were 2 July - 6 August 1985, 20 September - 18 October 1985, and 15 February - 2 April 1986. Although instrumentation problems and loss of meters were experienced during these deployments, sufficient data were obtained to characterize the environment and compare data from the FADS site with previous regional studies.

Comparisons of the properties of the current velocity fields for each of the current meter records can be made through the frequency distribution tables and plots of speed and direction time series presented in the Appendix. For the surface meter deployed during September-Octobter 1985, the mean current velocity was 22 cm/sec, compared with 7 cm/sec for the bottom meter and 4 cm/sec for the bottom meter during winter. Current data obtained by the DAISY system support these observations, indicating speeds on the order of 5-7 cm/sec oscillating between NNW and SSE directions during the short period of operation at FADS.

The three-hour low-pass current speed data (Figure I.2-16) indicate that the short-term current fluctuations are dominated by the semi-diurnal tidal component, as expected, and the absolute value of the current velocities are greater near the surface than in the bottom waters. Tidal ellipses for all three records (Figure I.2-17) indicate a strong NE-SW orientation for the surface water, a slight E-W orientation for bottom waters during the fall and a nearly rotational flow for bottom water during winter. Peak tidal velocities in the surface layer averaged approximately 30 cm/sec, reaching a maximum of 70 cm/sec during the passage of Hurricane Gloria. Bottom currents prior to the hurricane showed less variability in speed but continued oscillation in direction, averaging approximately 20 cm/sec. Following the storm, the bottom currents were generally less than 10 cm/sec. The same conditions existed during the winter deployment with bottom currents substantially less than 10 cm/sec

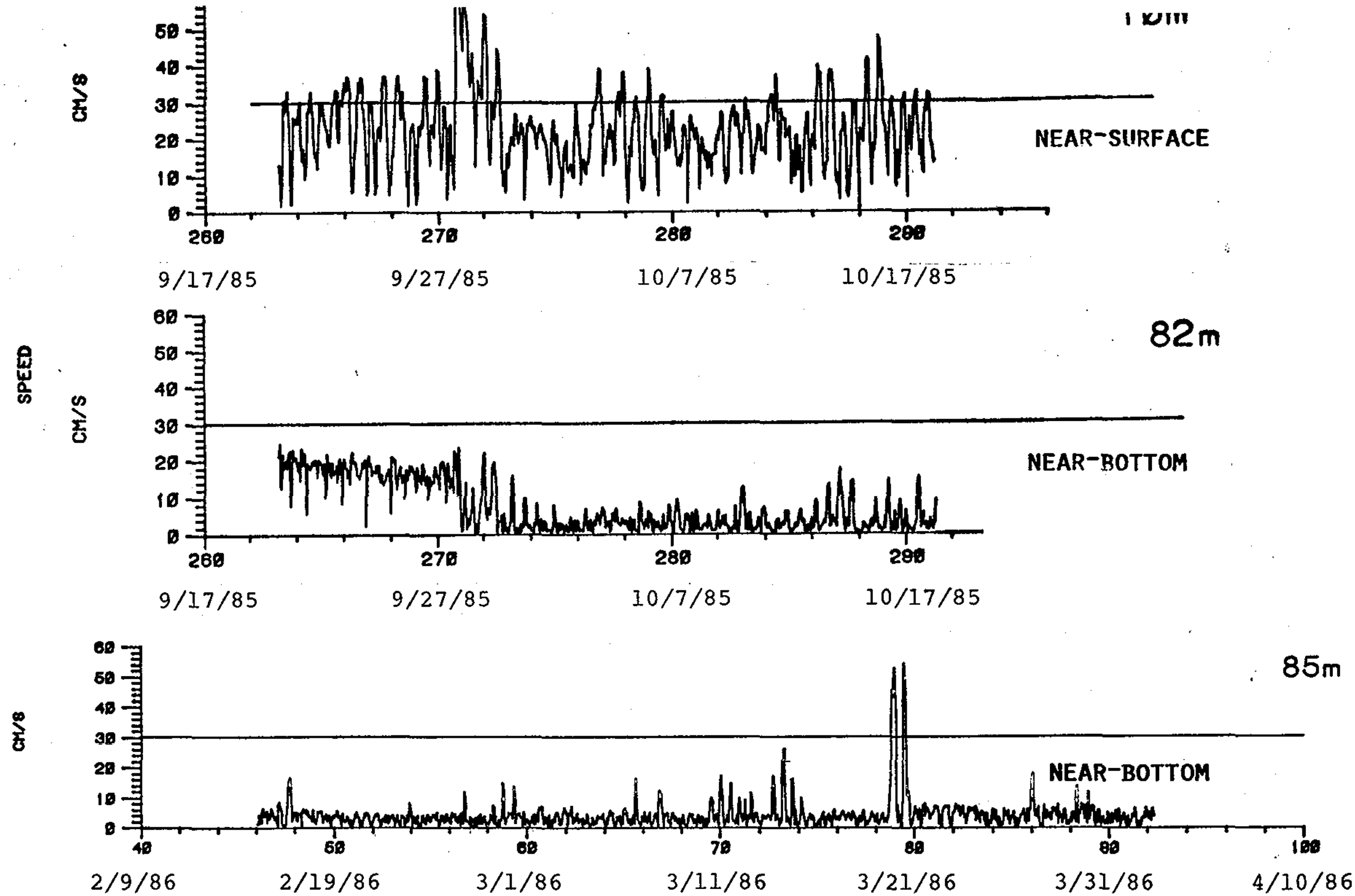
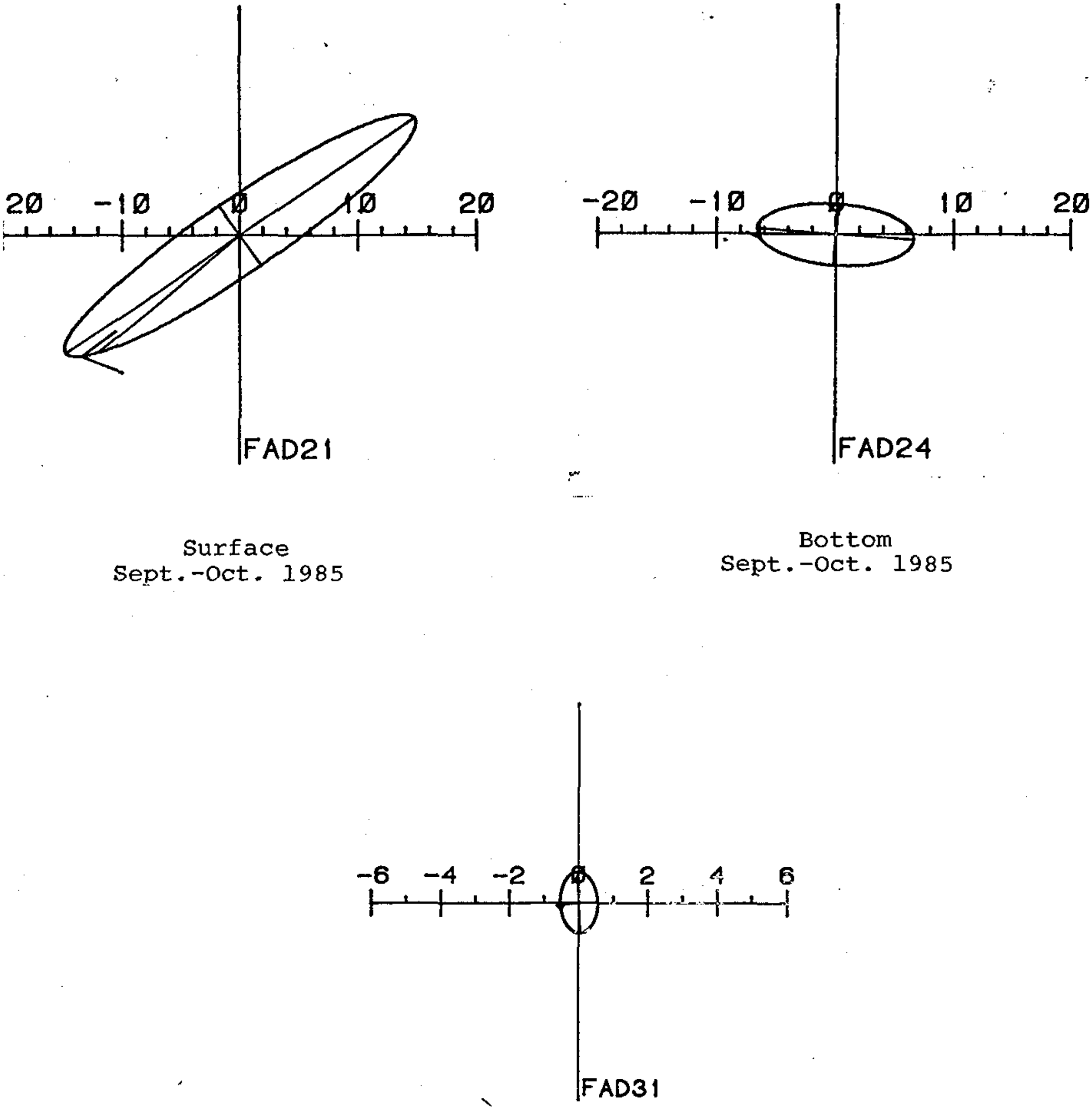


Figure I.2-16. Three hour low pass current speed (cm/sec) at FADS.



Surface
Sept.-Oct. 1985

Bottom
Sept.-Oct. 1985

Bottom
Feb.-April 1986

Figure I.2-17. Tidal ellipses from current meter data collected at FADS.

except for several larger peaks associated with meteorological events.

The expected response of the bottom currents to easterly storm events is clearly demonstrated by the record of the bottom meter during Hurricane Gloria (day 270 and 271) as shown in Figures I.2-18 and I.2-19. The direction of flow clearly deviates from the tidal fluctuations during the this period and maintains an easterly flow for approximately a 24 hour period. This is also shown in the forty-hour low pass vector plot (Figure I.2-19) which displays a net southeasterly drift during the period of the storm. Following the storm event, the net current transport remains extremely low.

During the winter deployment, several small perturbations to the oscillatory flow occur which may be related to meteorological events. On 16 February, a small peak velocity of 20 cm/sec occurs associated with the only easterly wind activity to occur in February (4 days from 16-20 February; maximum speed-17mph) which was associated with a low pressure cell passing offshore. Wave data obtained from the Portland ME sea buoy (Figure I.2-20) indicate that this was a significant storm event, producing wave heights of about 2 meters for several days. A similar storm occurred over a period of 13-17 March, with a low pressure cell passing directly over the FADS area which also resulted in bottom current velocities on the order of 20-25 cm/sec and wave heights of 2 meters in Portland. Potentially, the most significant event occurred on 21 and 22 March with bottom currents reaching nearly 60 cm/sec and wave heights slightly more than 3 meters. The spurious high current values occurring on 20 March do not appear to be real and may be the result of interference to the mooring by draggers which caused loss of the upper instruments. Winds during this period were from the northwest and simultaneous current measurements at Cape Arundel Disposal Site (CADS) did not indicate any anomalous current velocities during this period. Consequently, these points are not considered valid.

In summary, the current data obtained at FADS indicate that the expected circulation patterns suggested by Butman (1977) appear consistent with the observations obtained under this program. In most cases, the response to easterly storm events results in relatively low currents (20-25 cm/sec) which are not sufficient to resuspend material;, however, occasional events may occur which are sufficient to cause resuspension and transport of material. All cases of response to easterly storm events showed a southeast to south transport direction should material be placed in suspension.

I.2.3 Bathymetry

Massachusetts Bay is bounded on three sides by the Massachusetts coast. On the fourth side, the Bay opens to the Gulf of Maine between Cape Ann and Race Point on Cape Cod. The

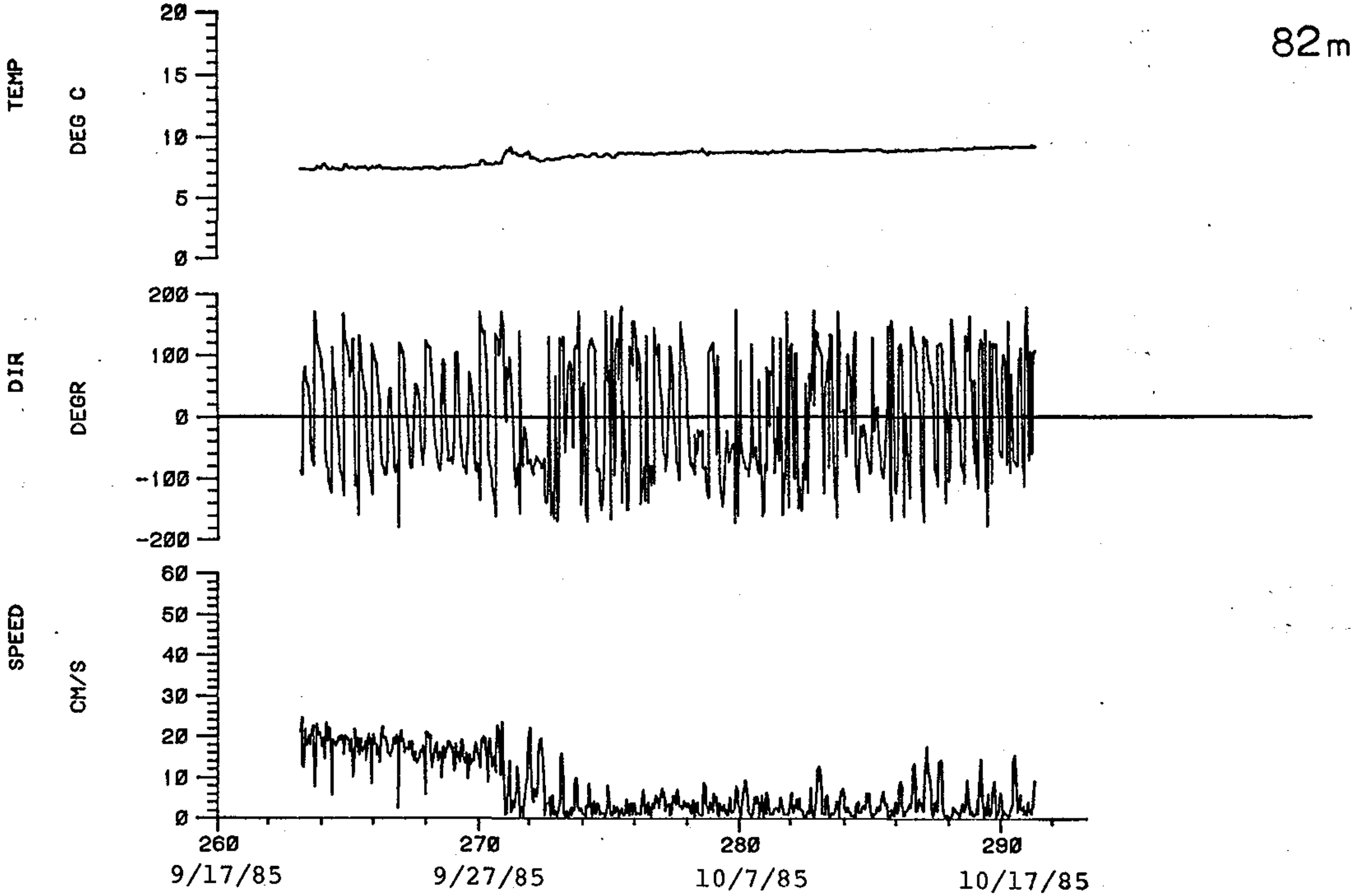


Figure I.2-18. Three-hour low pass (3-HLP) time series of temperature, current speed and direction at FADS at a depth of 82m (4m from the bottom) for the period of Sept. 20 - Oct. 18, 1985.

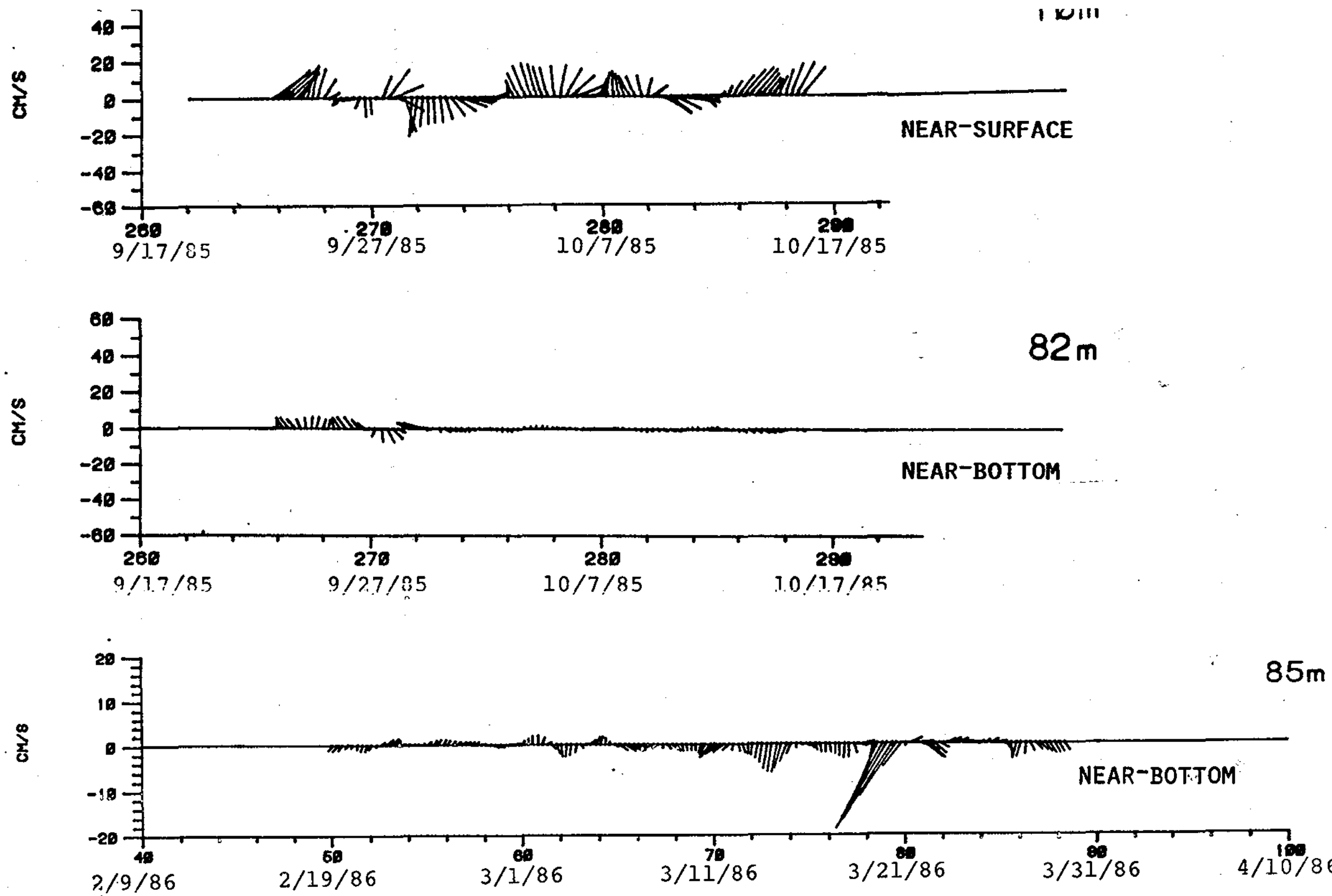


Figure I.2-19. Forty hour low pass (40-HLP) vector plot of current meter data collected at FADS.

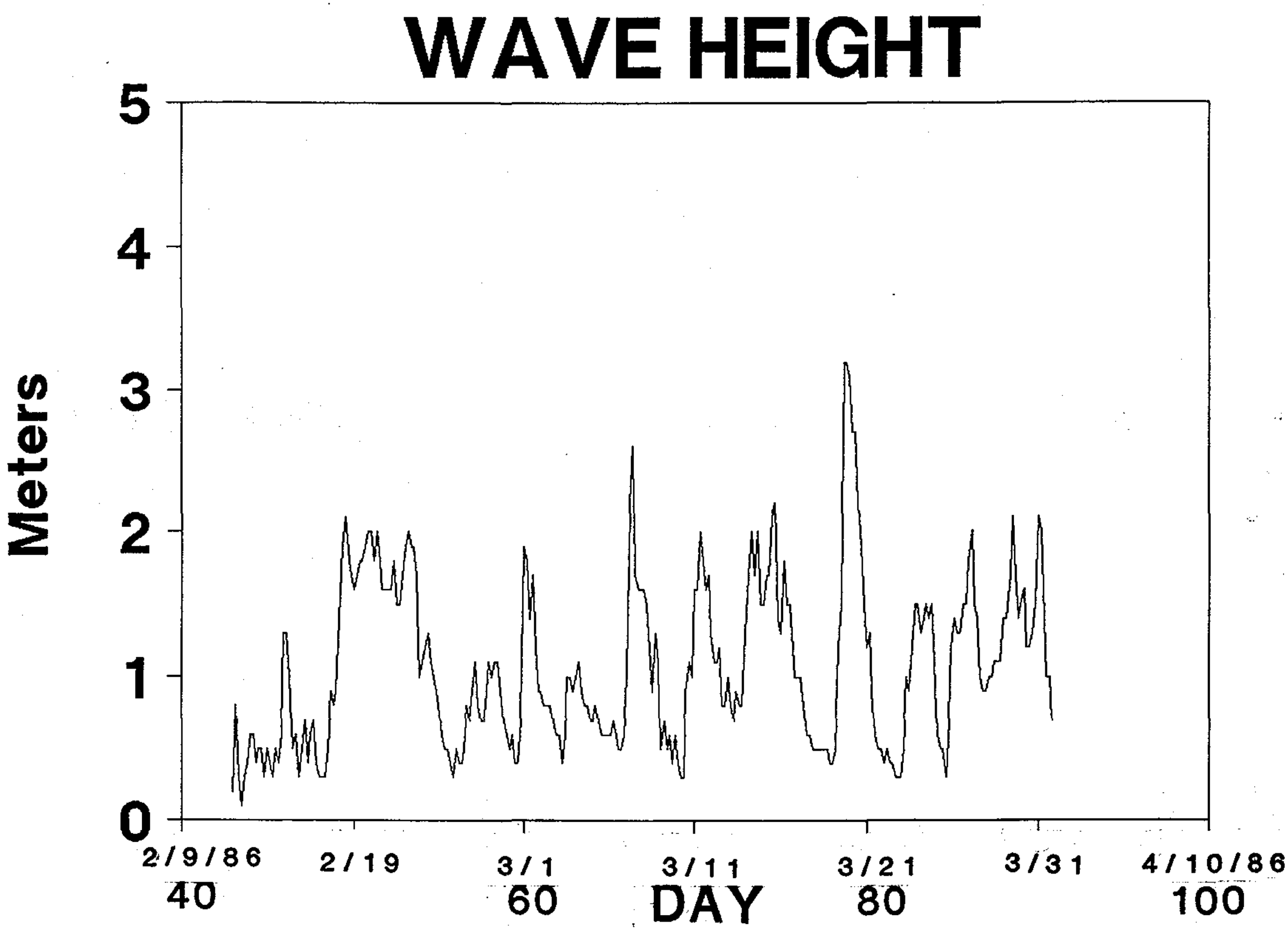


Figure I.2-20. Wave heights measured at Portland, ME automated meteorological buoy.

major topographic features of the Bay are Stellwagen Bank and Stellwagen Basin as shown in Figure I.2-21 (Butman, 1977). The eastern opening is partially blocked by Stellwagen Bank, which rises to within 20 m of the surface. Most of the Bay is less than 80 m deep, although maximum depth in Stellwagen Basin, located in the middle of the Bay immediately west of Stellwagen Bank, is over 100 m (Boehm et al., 1984). The shape of the sea floor is characteristic of an area that has experienced glacial scouring and sediment deposition, as well as post-glacial stream channeling and subsequent modification of bottom contours by advancing post-glacial seas (Padan, 1977).

Bathymetric surveys of the general Massachusetts Bay area including FADS have been conducted by the National Ocean Survey and plotted on an Outer Continental Shelf Resource Management Map (U.S. Department of Commerce, 1980d). Some bathymetric records were made at FADS as part of a short-term underwater television survey (SubSea Surveyors, 1973). More detailed bathymetric surveys were made at FADS under the DAMOS program by NUSC (1979b). These surveys (Figure I.2-22) indicated a broad depression in the south central region of the site with shoaling in the northeast area toward Stellwagen Bank, and in the north central region toward a smaller feature possibly associated with the bank. There was no discernable mound as a result of previous dredged material disposal (NUSC, 1979b). Surveys made as part of the 1983 dredged material disposal operations from Boston Harbor also showed no formation of a disposal mound (SAIC, 1985). Bathymetric surveys were also made at a new site, Foul Area-South (FAS), prior to and following parts of the same disposal operation, and results (Figure I.2-23) indicated no significant vertical signature of dredged material at this disposal site (SAIC, 1985).

On 17 and 18 October 1985, a combined side scan and bathymetric survey was conducted at FADS to define present conditions and to delineate the detectable spread of dredged material previously deposited within the site. Earlier side scan surveys of this general region had been conducted in the past by EPA and NOAA (Lockwood, et al., 1982) and by the New England Division under the DAMOS Program. A secondary objective of this survey was to compare the present results with the previous surveys and to expand the area of coverage to the east, because earlier surveys concentrated on the disposal site to the west which was used prior to redesignation of the site in the mid 1970's.

The results of the bathymetry survey (Figures I.2-24, I.2-25 and I.2-26) show that the topography of the disposal site is characterized by a relatively flat, featureless bottom throughout most of the site with the notable exception of steep shoaling in the northeast and northwest quadrants. The depths throughout the smooth, featureless area are on the order of 85-90 meters, with maximum depths occurring in a broad depression in the south central portion of the site. The shoals in the

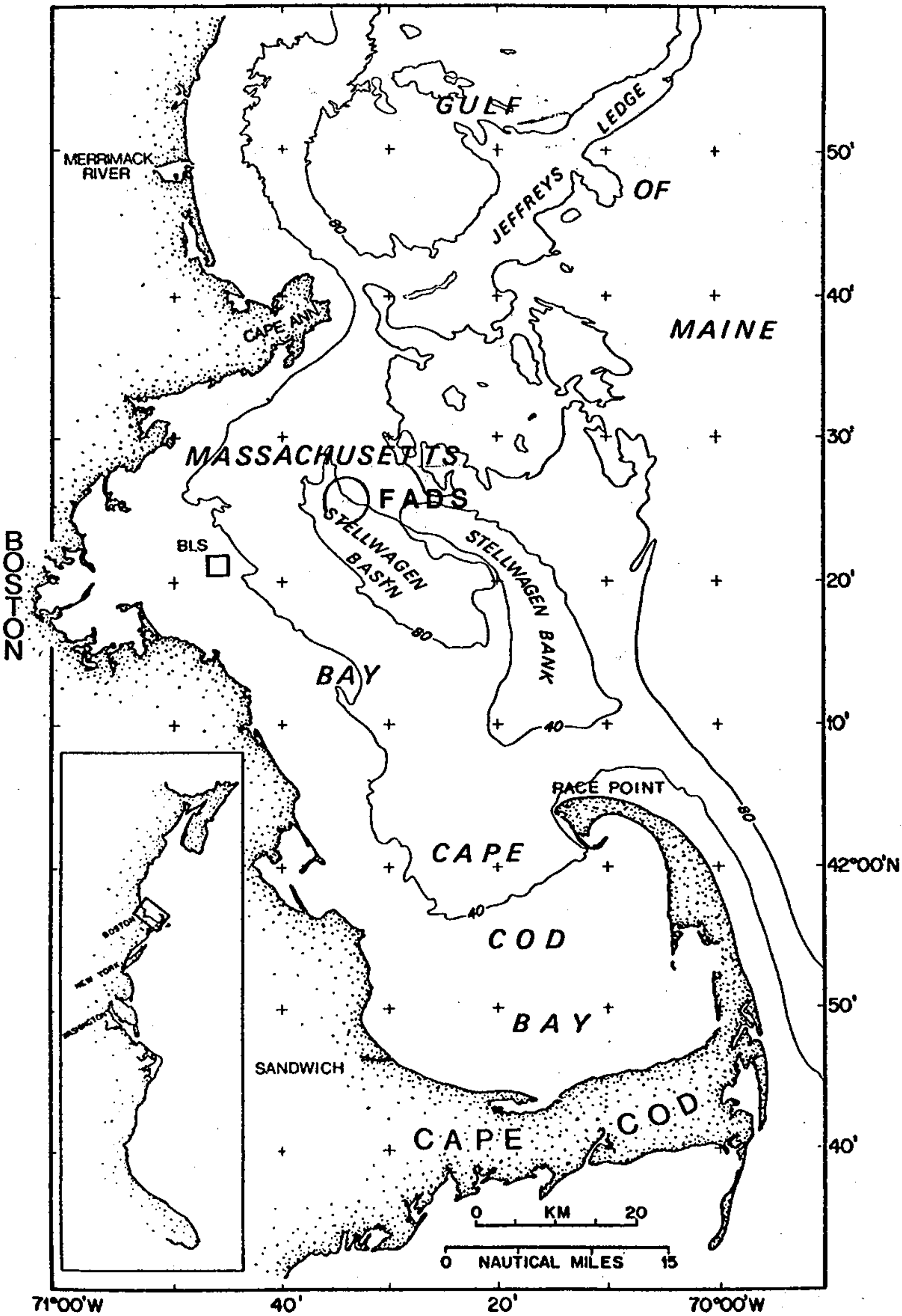


Figure I.2-21. Major bathymetry features in Massachusetts Bay (Butman, 1977).

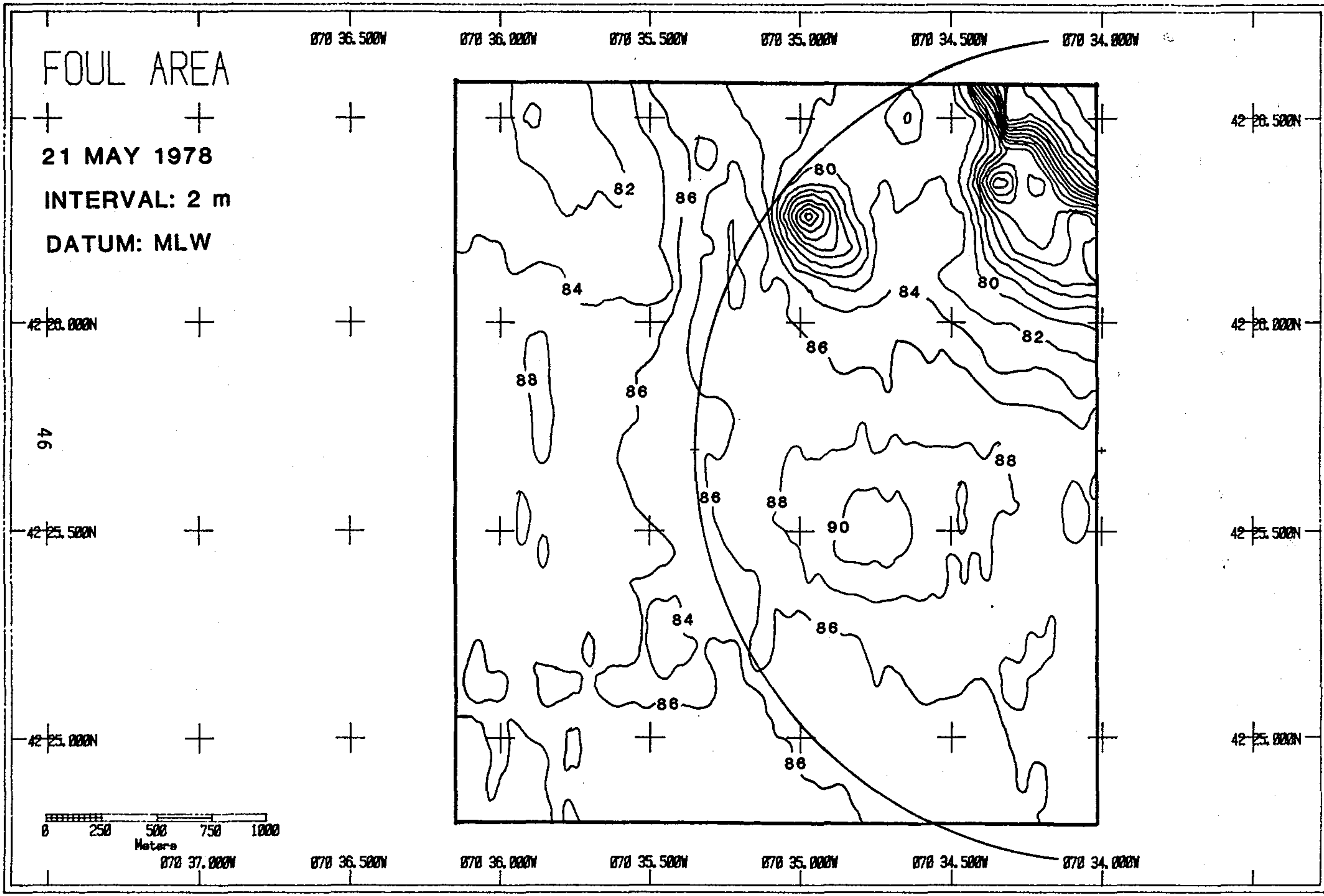


Figure I.2-22. Depth contour plot of bathymetric data collected at FADS on 21 May 1978 (NUSC, 1979).

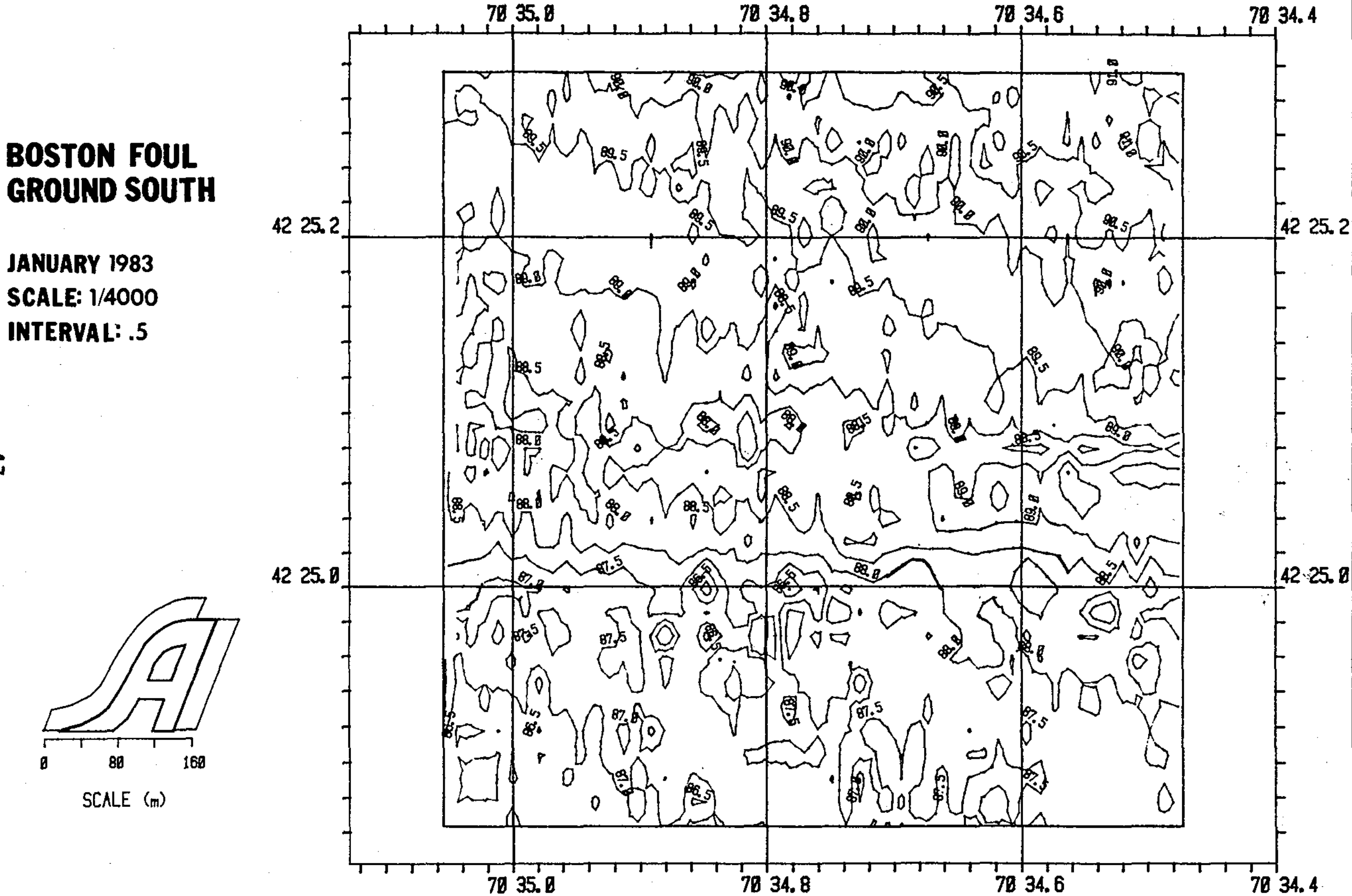


Figure I.2-23. Depth contour chart of Foul Area - South (FAS) Site.

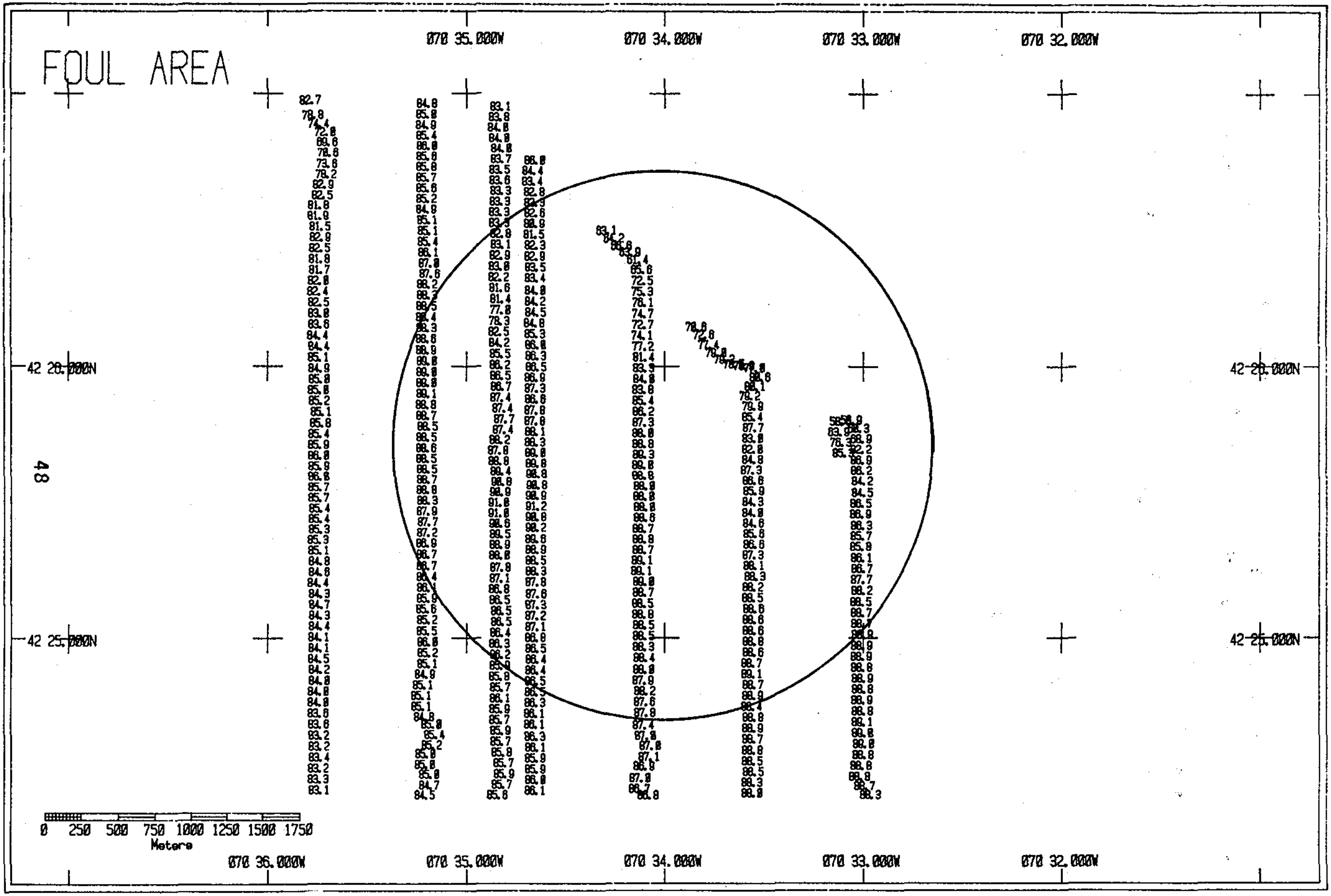


Figure I.2-24. Depth smooth sheet generated from bathymetric data collected at FADS during October 1985.

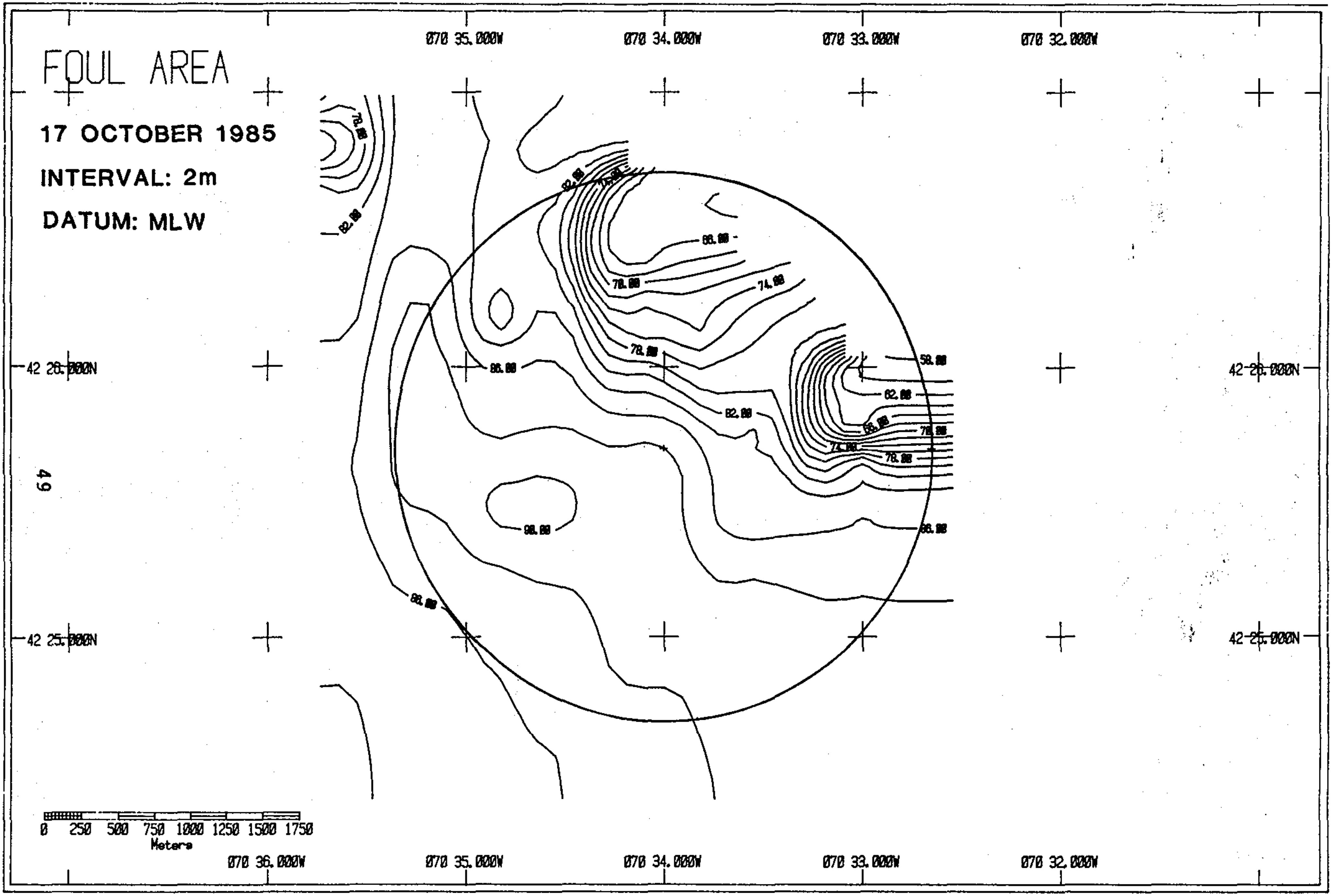


Figure I.2-25. Depth contour chart generated from bathymetric data collected at FADS during October 1985.

FOUL AREA DISPOSAL SITE
17 OCTOBER 1985

VERTICAL EXAGGERATION: 40X

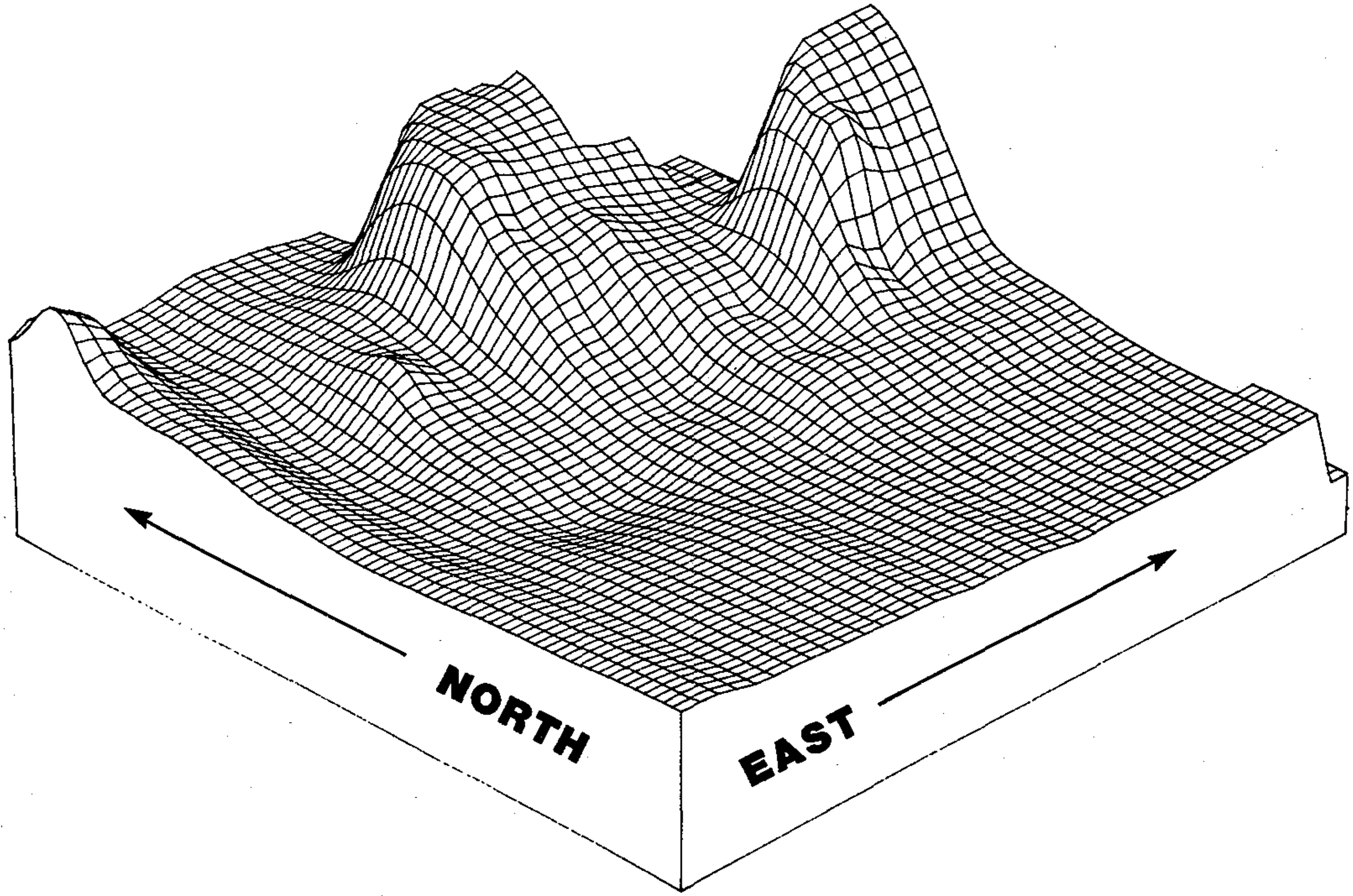


Figure I.2-26. Three dimensional plot generated from bathymetric data collected at FADS during October 1985.

northeast quadrant, with minimum depths of 57 meters within the site, represent glacially formed features and are associated with Stellwagen Bank to the east of the site. The smaller shoal in the northwest section of the survey is a small, circular rise which appears to be a single, separate feature, although derived in the same manner as Stellwagen Bank.

There are no significant topographic features related to dredged material disposal; however, acoustic profiles do show indications of more varied microtopography and greater acoustic reflectivity in areas where dredged material may be expected to occur than in areas of natural silt bottom (Figure I.2-27).

I.2.4 Sedimentology

The sediment composition in Massachusetts Bay as shown in Figure I.2-28 (from Schlee et al., 1973) is dominated by heterogeneous sediments composed primarily of glacial till; this area was glaciated twice during the Ice Age (Willett, 1972; Setlow, 1973). The floor of Massachusetts Bay is characterized by outcroppings of bedrock interspersed with areas of cobble, gravel, sand, with some of the deeper areas grading into fine muds with a high clay content (Willett, 1972; Schlee et al., 1973). Proceeding inshore towards the coastline, spatial variability in grain size increases, with sands dominating along high energy exposed areas and silts and clays within more sheltered embayments. These distributions are interrupted irregularly by glacial till deposits and occasional bedrock outcrops.

FADS is located within the northwestern corner of the Stellwagen Basin, an area dominated by fine silts and clays. Within the site itself, sediments consist primarily of fine-grained silts and clays with moderate to high concentrations of organic carbon, characteristics representative of deposited dredged materials. Immediately adjacent to the site, mean grain sizes increase slightly with silts dominating distributions along a northwest-southeast tending line extending over distances in excess of 10 nm from the site. Along an east-west tending track, the initial dominance of fines changes to coarser grained materials ranging to glacial gravels on Stellwagen Bank. Overall, the distributions indicate that FADS lies within the depositional basin in the center of the Bay.

Martin and Yentsch (1973) reported that sediment samples taken at FADS were different from those collected at a reference station north of FADS. Grayish-green mud, characteristic at depths greater than 80 m, was found to be covered with a fine deposit of black mud. This surface layer was absent at the reference station.

Gilbert (1975) described the ocean floor at FADS as being composed principally of greenish gray mixtures of fine-

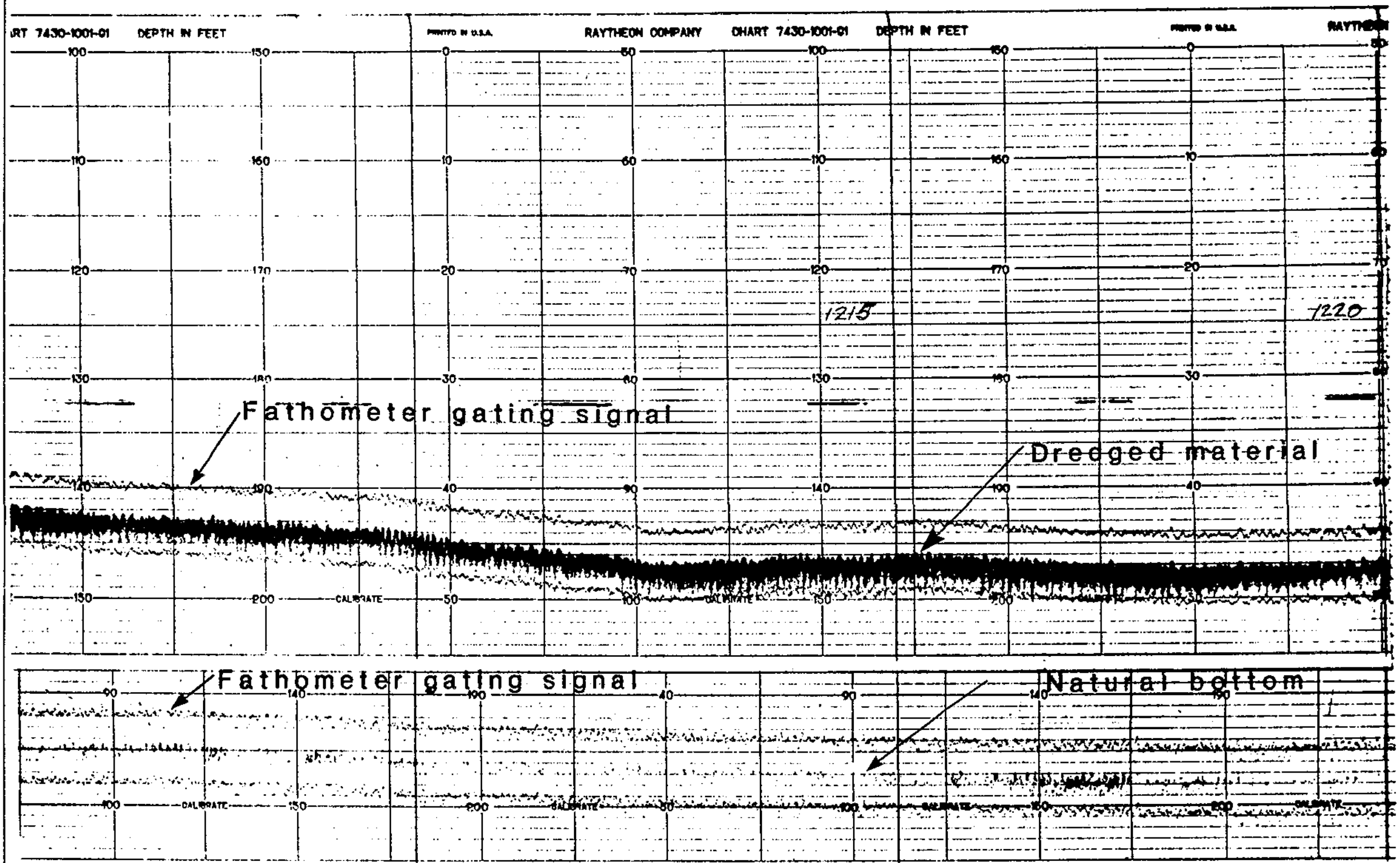


Figure I.2-27. Comparison of fathometer record recorded over dredged material and natural bottom at FADS.

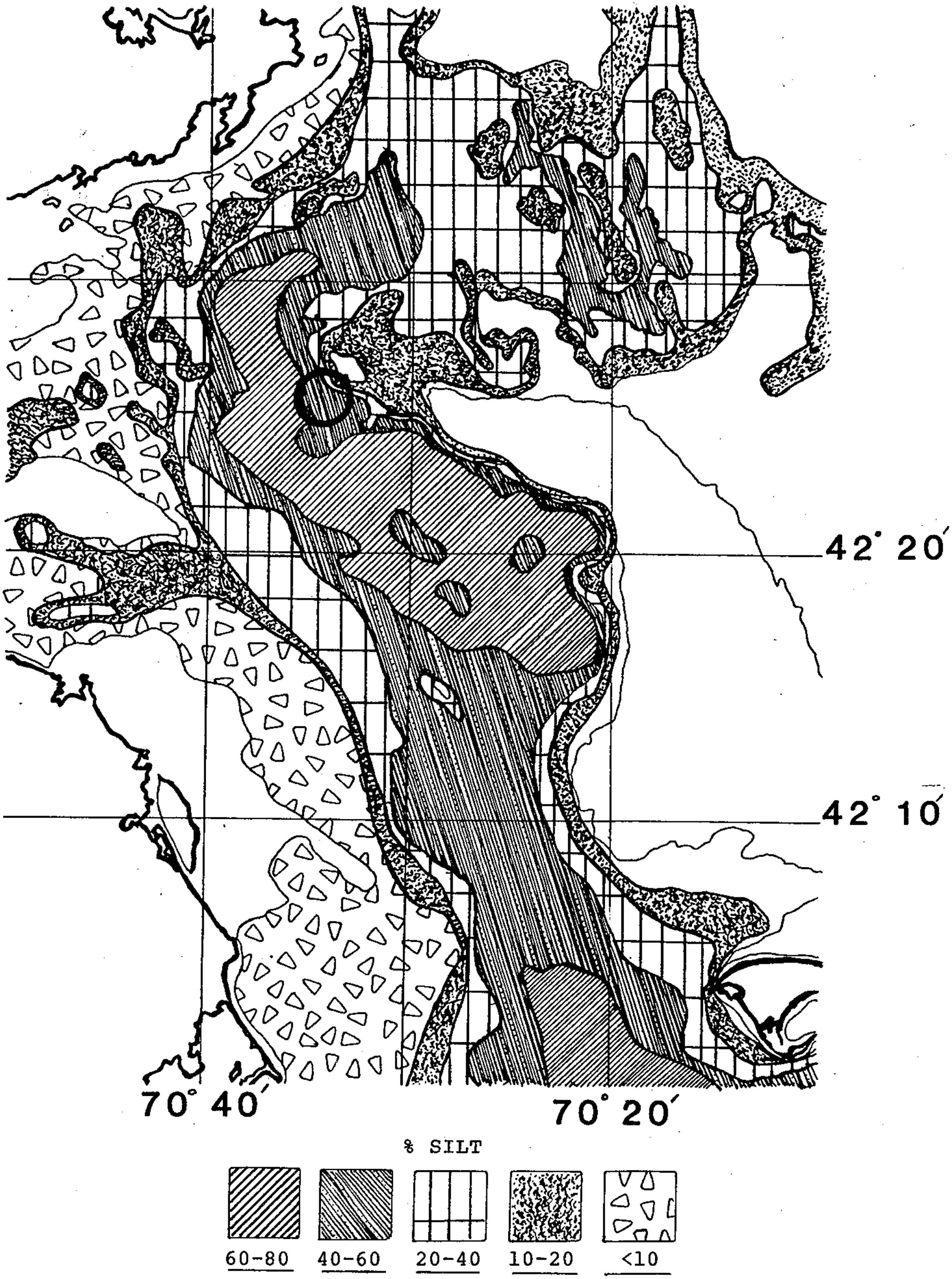


Figure I.2-28. Distribution of silt in Massachusetts Bay. (From Schlee et al., 1973) grained silt and clay. In the northeast portion of FADS, the bottom was composed principally of coarse sand and gravel. Grain size analyses indicated occurrence of fine-grained sediment expected in an area of relatively deep water where bottom currents would not be expected to be directly affected by wind-induced wave action.

As a result of the side scan sonar survey, the bottom at FADS was characterized by four distinct facies distributed as shown in Figure I-2-29. The facies can be characterized according to representative side scan sonar records taken from the locations shown in Figure I.2-30 and presented as Figures I.2-31 and I.2-38:

Type 1) Hard sand, cobble and gravel bottoms associated with steep topographic rises (Figure I.2-31),

Type 2) Soft smooth sediment with small, high reflectance targets randomly distributed over the bottom (Figure I.2-32),

Type 3) High reflectance bottom indicative of dredged material which has specific characteristics including:

A - Extremely coarse dredged material with high reflectance and microtopography on the order of one or two meters as evidenced by shadows (Figure I.2-33).

B - Isolated mounds or deposits of dredged material at some distance from the major areas of accumulations, often consisting of coarse material (Figure I.2-34),

C - Circular high reflectance areas with no relief, frequently adjacent to each other in a consistent linear pattern and sometimes exhibiting crater like signatures indicative of a specific disposal event (Figures I.2-35 and I.2-36),

D - Dredged material with a stronger reflection than natural sediment but less intensity than that described in 3A and lacking the larger microtopographic features (Figure I.2-37),

Type 4) Soft, featureless silty bottoms extending over large areas with occasional trawl marks providing small scale topographic relief (Figure 2-38).

A substantial amount of information concerning the characteristics of the site, previous disposal operations and the

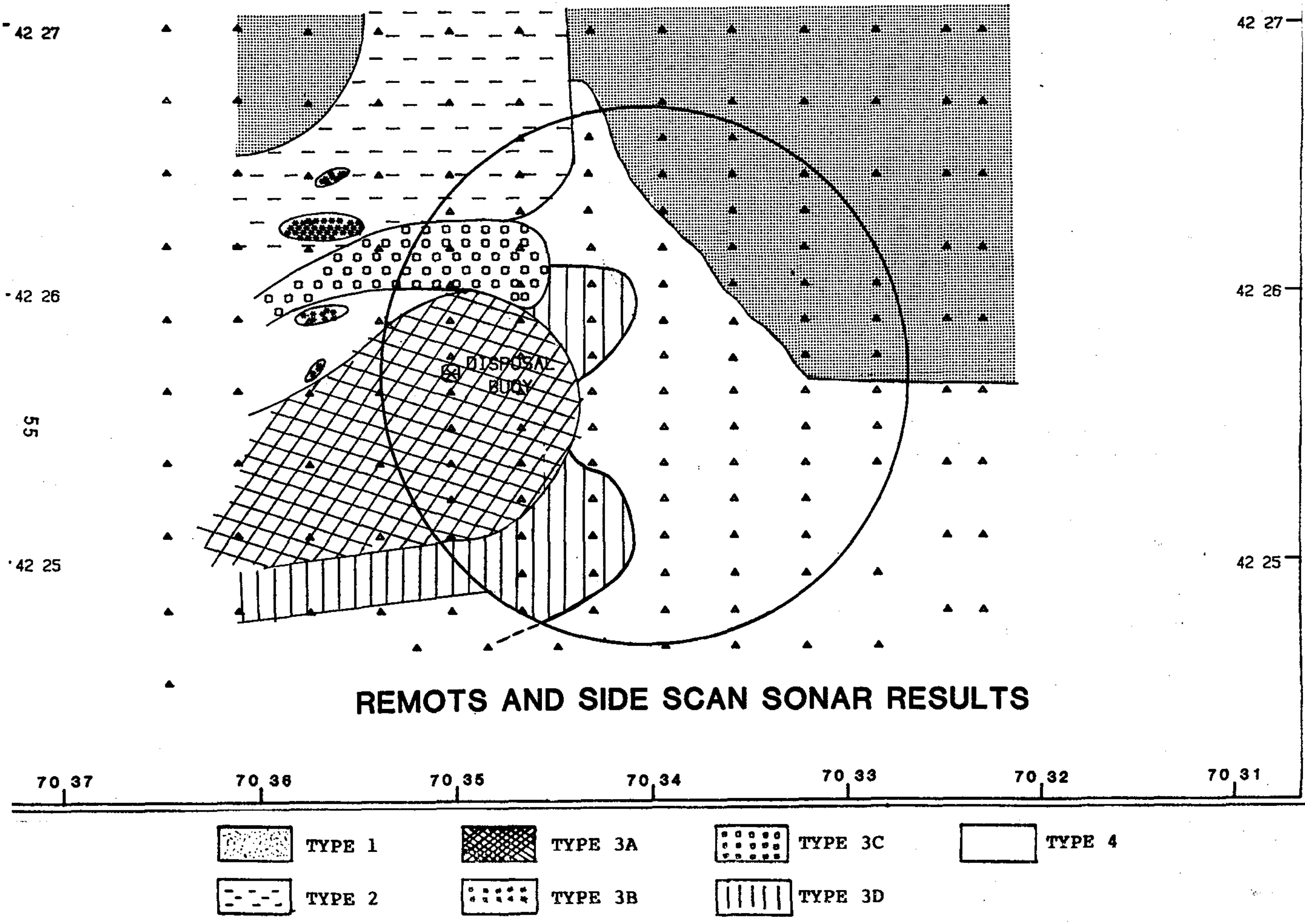


Figure I.2-29. Distribution of sediment types at the Foul Area.

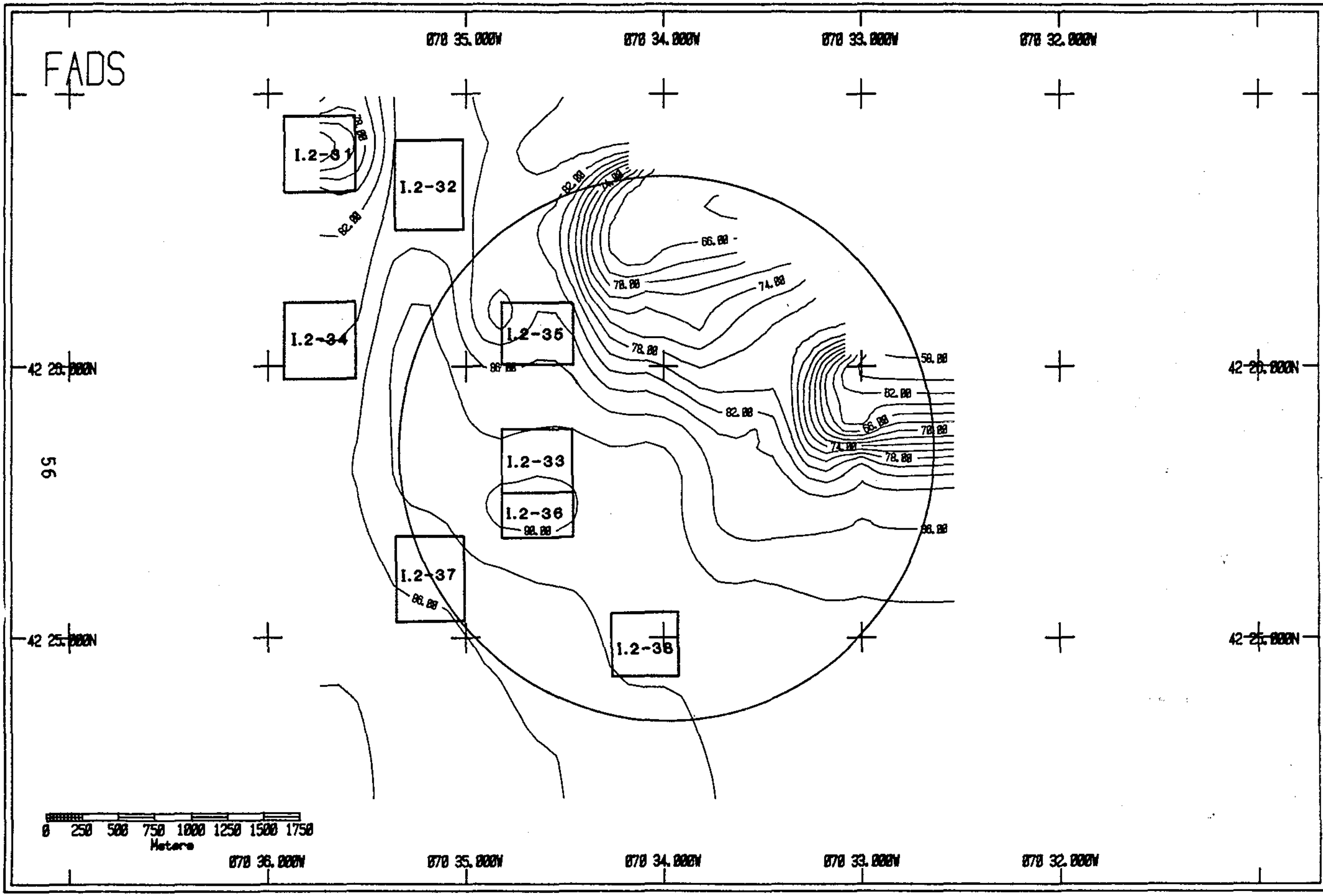


Figure I.2-30 Location of side scan sonar records discussed in Section I.2.4.

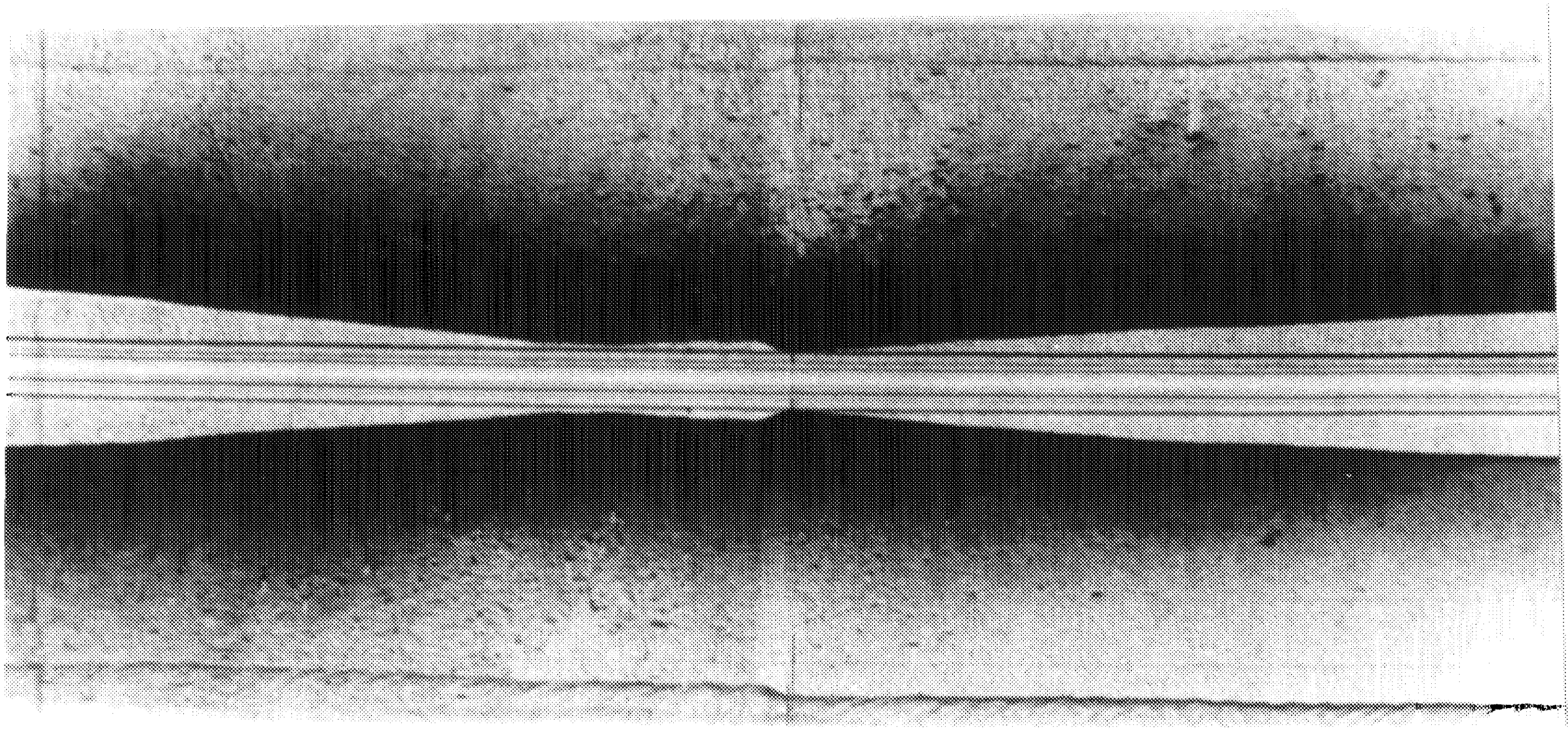


Figure I.2-31. Type 1 side scan sonar record, Foul Area Disposal Site. Hard bottom with sand, gravel and exposed rock associated with shoaling in NE Quadrant of site.

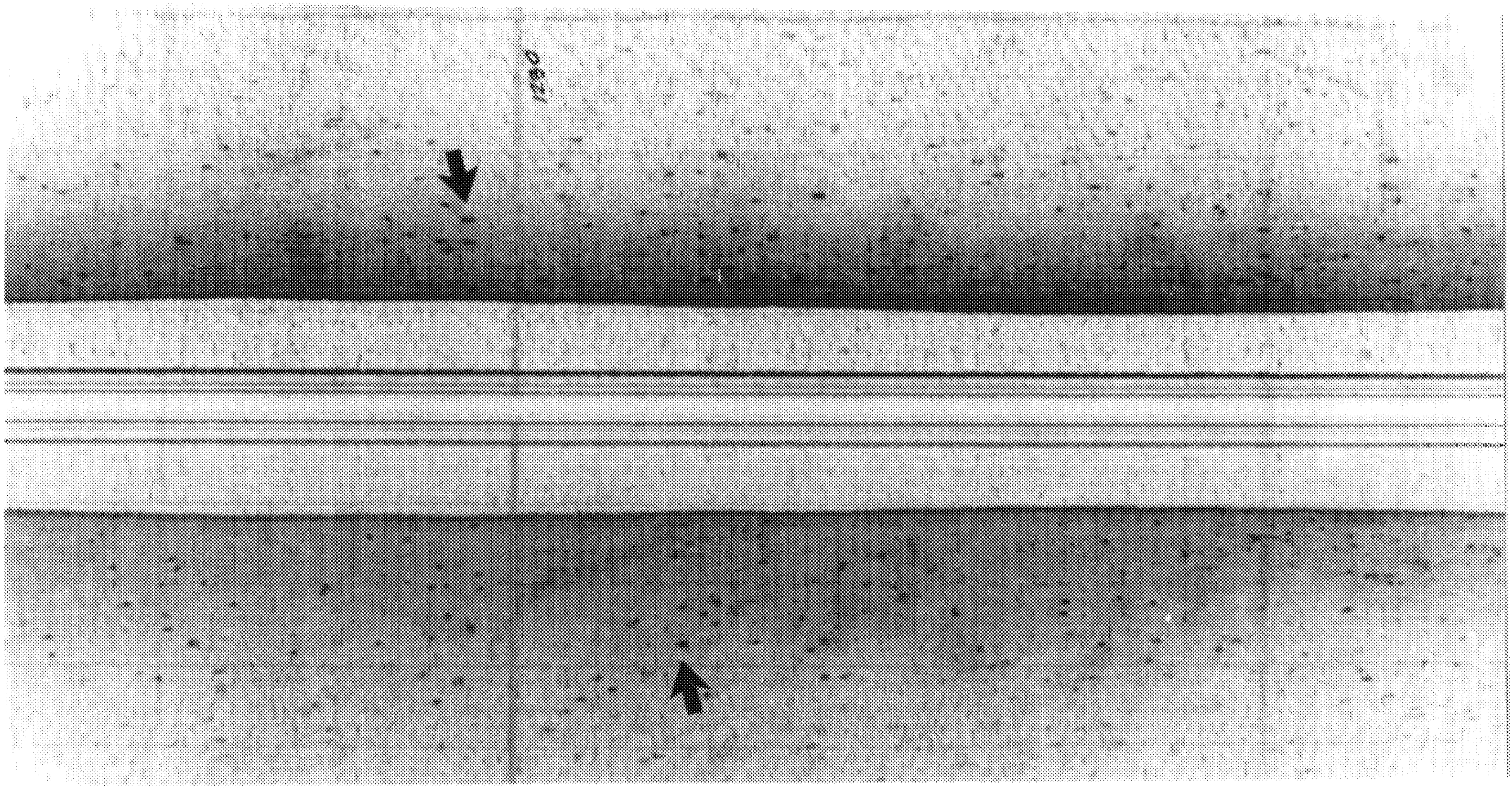


Figure I.2-32. Type 2 side scan sonar record, Foul Area Disposal Site. Soft, natural silt bottom with distinctive acoustic targets caused by chemical or low-level radioactive waste, indicated by arrows.

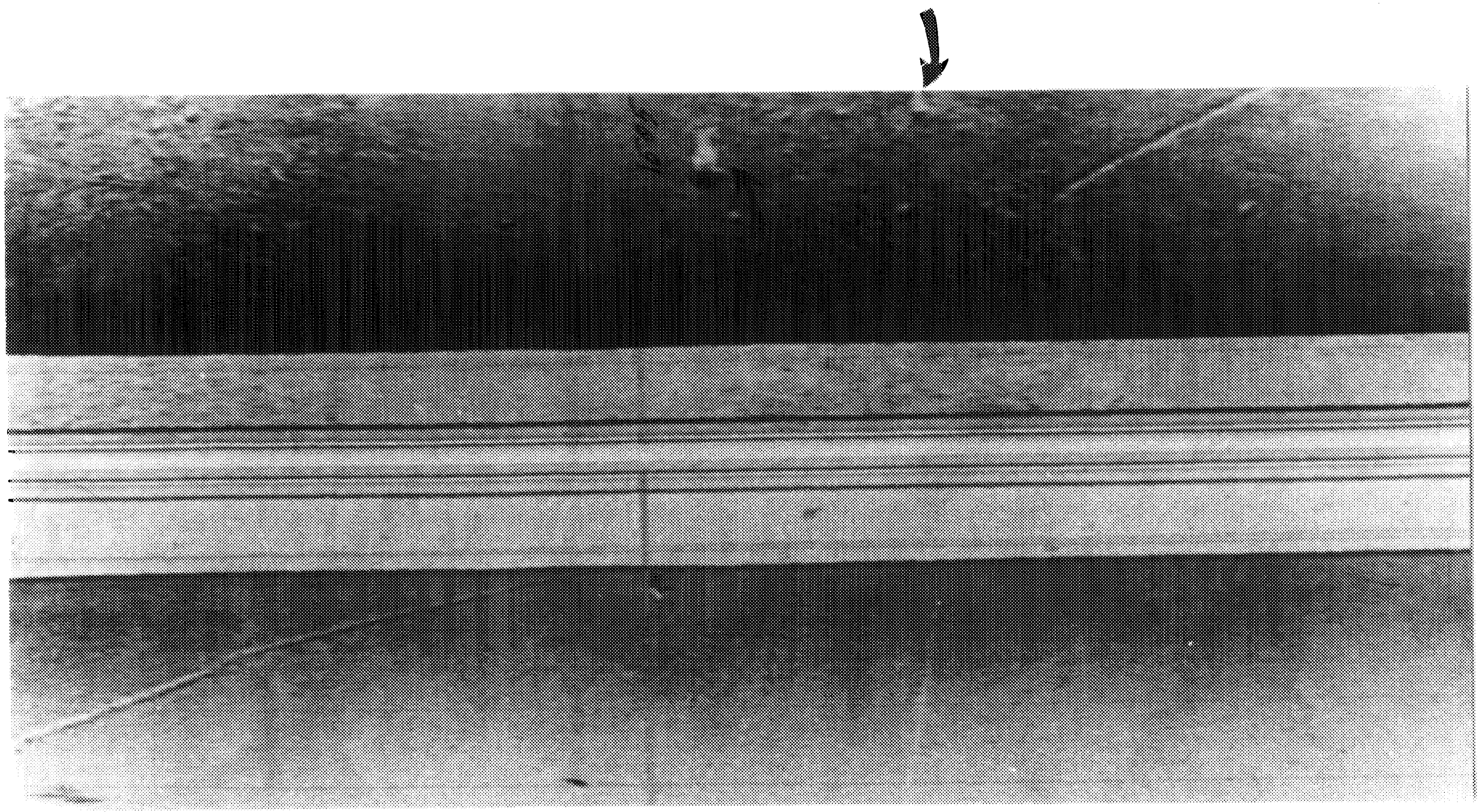


Figure I.2-33. Type 3a side scan sonar record, Foul Area Disposal Site. Coarse dredged material deposit near disposal point with accumulation of large clay clumps indicated by shadows. (Arrows point to clay clumps.)

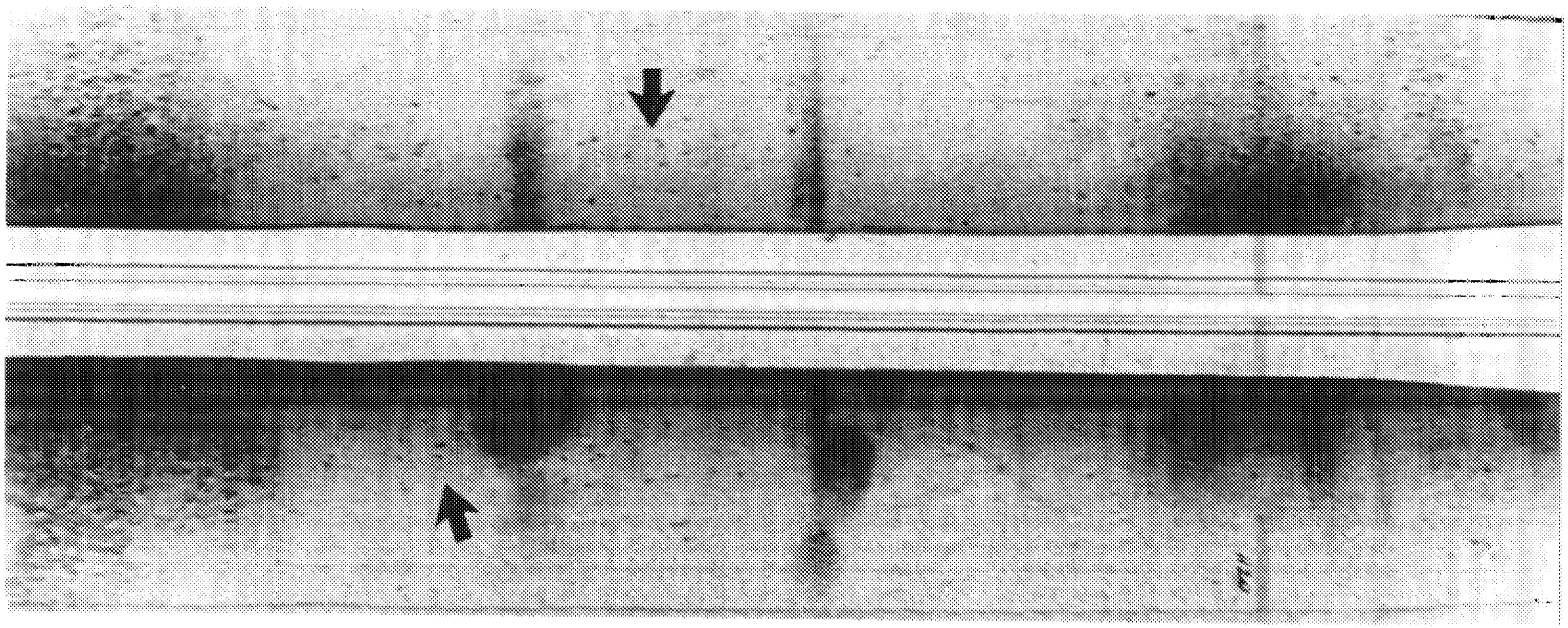


Figure I.2-34. Type 3b side scan sonar record, Foul Area Disposal Site. Isolated mounds of coarse dredged material at significant distance (1500m) from disposal point. Arrows point to acoustic targets caused by chemical or low-level radioactive waste.

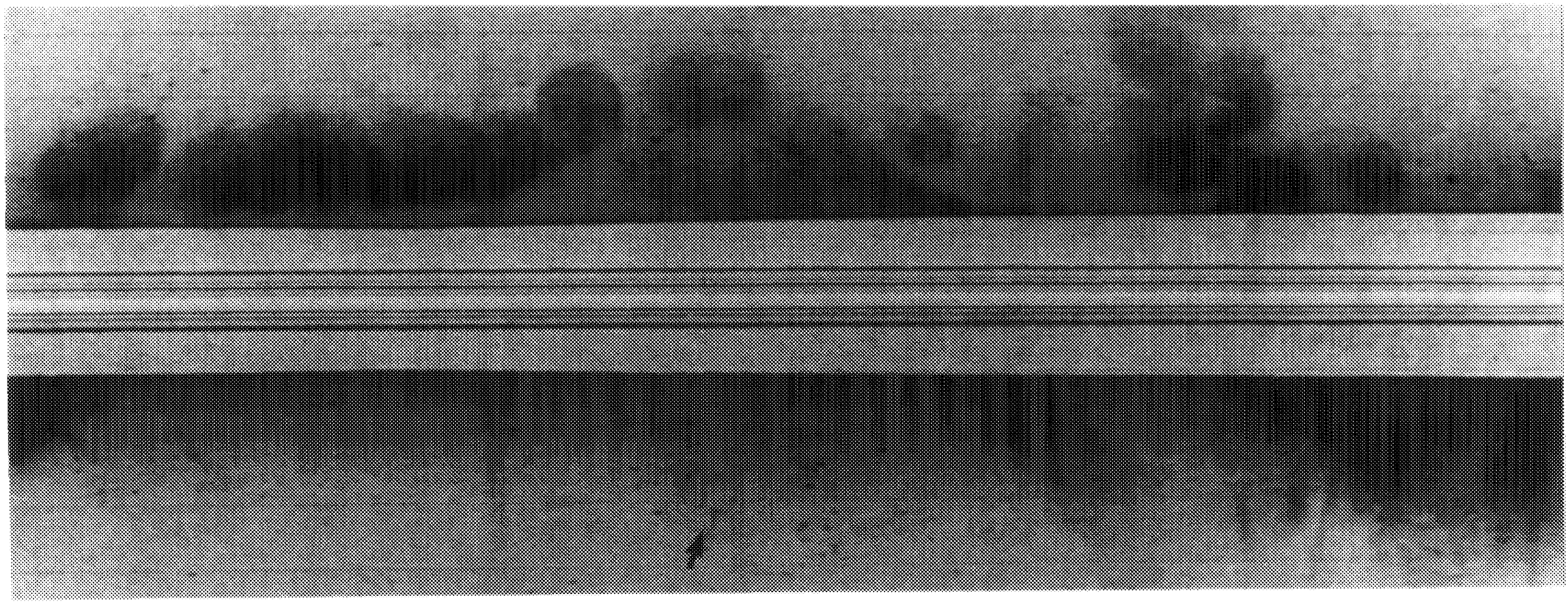


Figure I.2-35. Type 3c side scan sonar record, Foul Area Disposal Site. Circular, high reflectance areas in linear pattern, indicative of dredged material disposal activity. Arrow points to acoustic target caused by chemical or low-level radioactive waste.

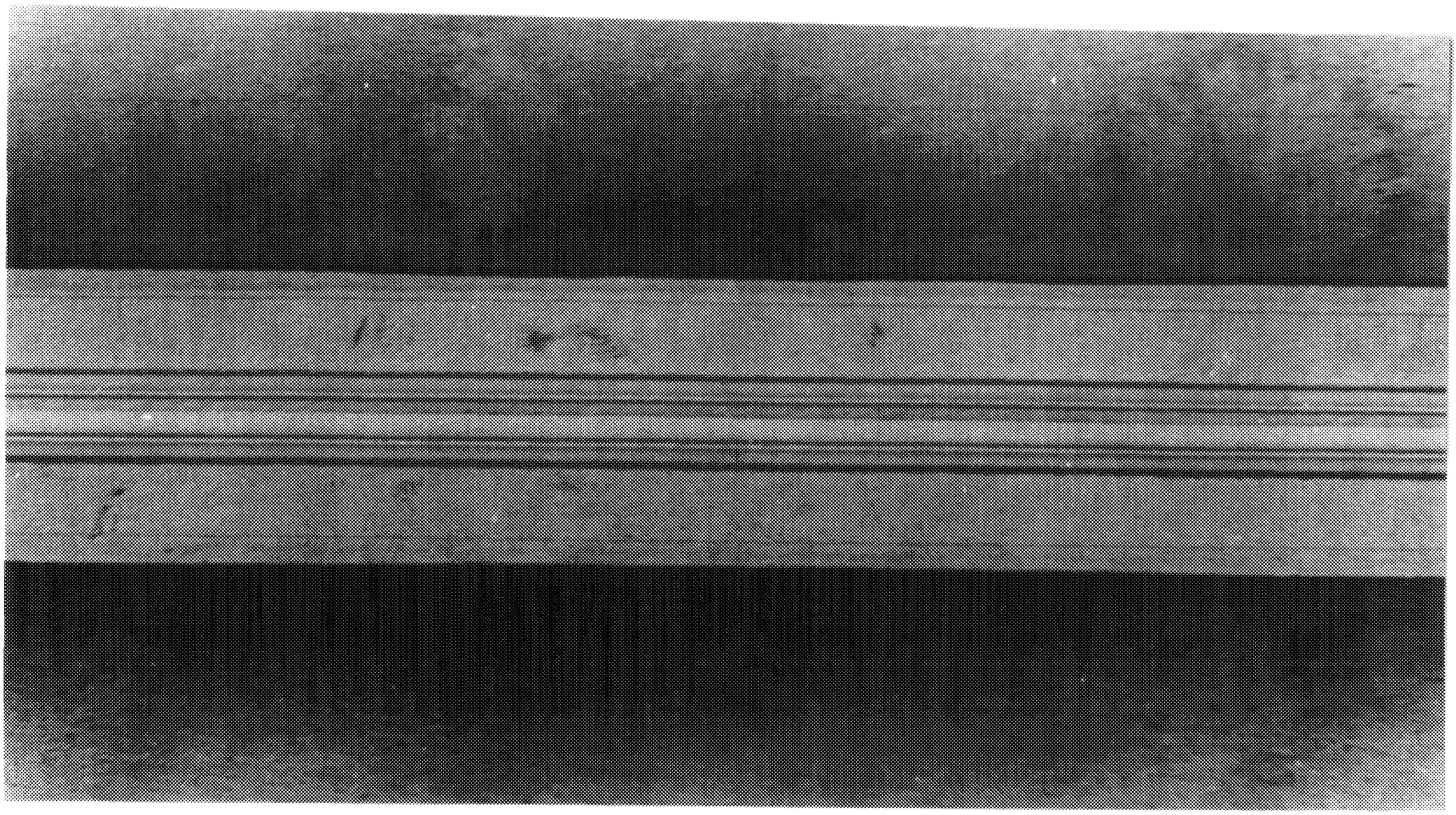


Figure I.2-36. Type 3c side scan sonar record, Foul Area Disposal Site. Circular high reflectance area with crater-like signature indicative of dredged material disposal activity.

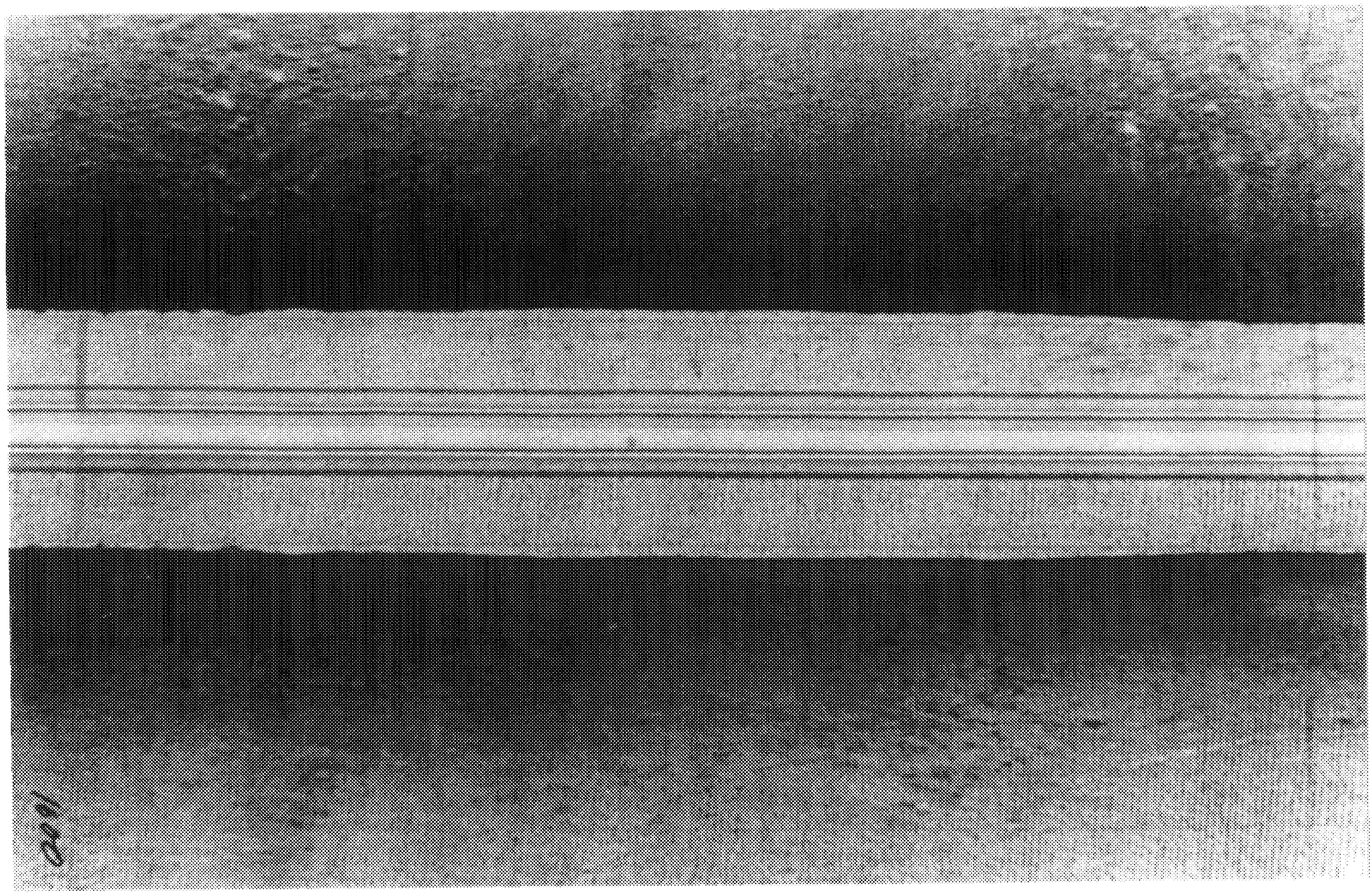


Figure I.2-37. Type 3d side scan sonar record, Foul Area Disposal Site. Dredged material deposit with less intense acoustic reflection, indicating margins of disposed dredged material deposits.

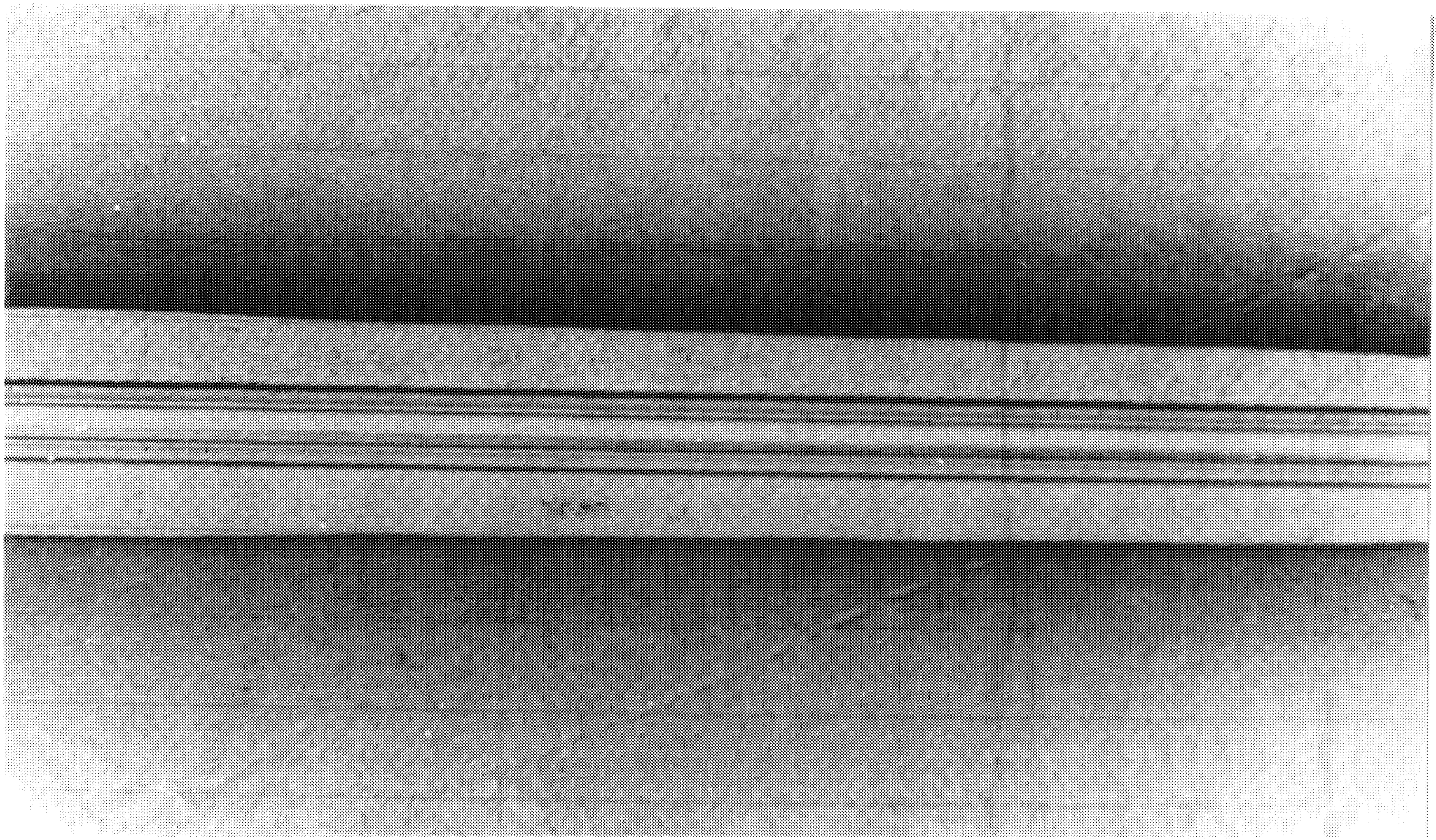


Figure I.2-38. Type 4 side scan sonar record, Foul Area Disposal Site. Soft, silty natural bottom with low acoustic reflectance.

stability of dredged material in this area can be determined from this chart.

Of the two types of natural bottoms, the Type 1 areas (hard sand) are associated with the shoals in the northeast portions of FADS. In the northeast, the sandy bottom is related to the shoaling topography approaching the Stellwagen Bank. To the northwest beyond the margins of the site, the sand and coarse sediment are associated with an isolated topographic feature which appears to be a relict glacial formation created in the same manner as the Bank.

The soft, featureless silty bottoms are found extensively throughout the southeastern portion of the study area and are the predominant natural bottom throughout the region of the disposal site. The dredged material and other targets are deposited on top of this natural sediment.

In the northwest quadrant of the disposal site, extending to the west of the study area, the bottom is covered by small targets which have been identified through underwater television to be canisters and drums deposited on the bottom. It is known that both chemical and low level radioactive wastes have been deposited at the site in the past either in cement canisters or 55 gallon drums (Lockwood et. al, 1982). However, it is impossible to determine which targets represent which type of waste from the side scan record. The previous surveys by NOAA and EPA indicate that these targets are generally concentrated west of the interim disposal site (Figure I.2-39), although it is highly probable that many canisters or drums are covered with dredged material in the west central portion of the site.

The dredged material detected by sidescan sonar is generally concentrated in the vicinity of the disposal buoy placed by the Coast Guard at 42°25.66'N, 74°35'W, although it has spread over a relatively large area for a number of reasons. The major disposal projects at this site during the past several years have been associated with dredging of the Chelsea and Mystic Rivers in Boston Harbor and President Roads at the entrance to the harbor. During 1983, all of the material from the rivers was dredged by clamshell techniques and deposited east of the Coast Guard Buoy by scows towed by tugs. Material from President Roads was partially dredged by clamshell and deposited by scows at a taut-wire mooring, located at 42°25.39'N, 74°34.54'W, approximately 850 m southeast of the Coast Guard Buoy. The remainder of President Roads was dredged by a hopper dredge and deposited at the same location under Loran-C control.

Examining the distribution of dredged material, it is apparent that the high reflectance material with microtopographic features is concentrated in the vicinity of the disposal buoy and extends westerly into the historically used site located just west of the currently designated interim disposal site.

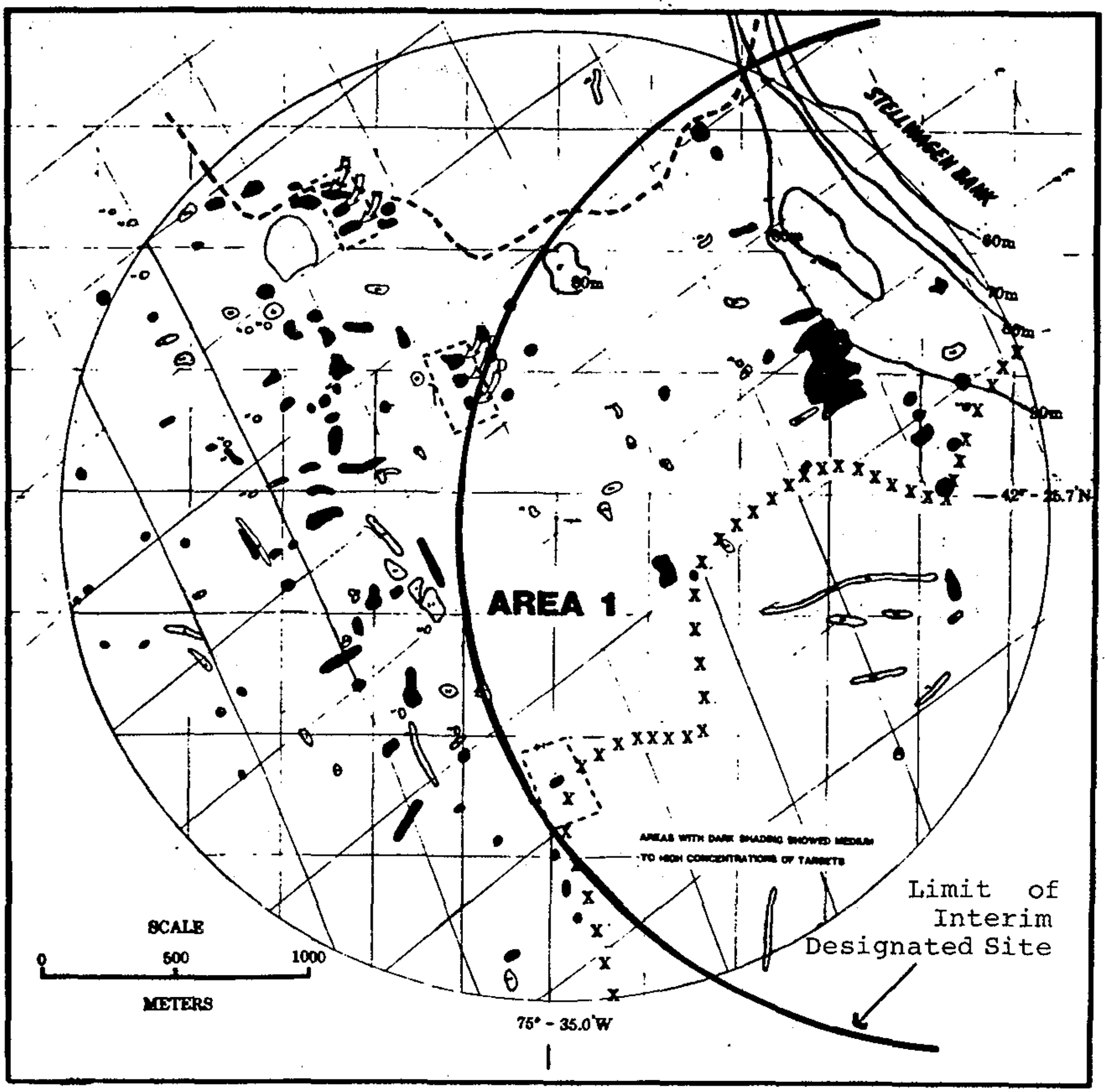


Figure I.2-39. Side scan survey analysis, 1981 (Lockwood et al., 1982).

----- : southern boundary of uniform bottom containing a large number of hard targets.

xxxxx : northern boundary of uniform bottom containing a few dredged material deposits.

: areas of medium to high densities of targets.

Progressing to the south, the intensity of the dredged material signature decays, although the sediment present has substantially more reflectance than the natural bottom. To the north, the boundary between the coarse dredged material and natural bottom is much more pronounced, and material is seen as isolated deposits of coarse material or as the circular deposits with relatively high reflectance.

This distribution is generally explained by the procedures used in disposal at the site. During the clamshell and scow operations, the tug operators would approach the buoy from the northwest, swing to the east, and dump material as they or the scow passed the buoy. Consequently, there were few dumps to the north, but when they did occur they can now be seen as distinct entities on the side scan record. As the scow passed the buoy, most of the material was deposited; however, not all of the material may have fallen from the scow at once, and because the tug was moving in a southerly direction, the tendency was for the deposit to spread to the south. Because coarse dredged material is observed as much as 1000 m to the north of the buoy indicates that careful control of disposal was not exercised during the initial disposal operation. However, it is also apparent that because this material still has a distinct signature two years after disposal, there are very few forces acting on the material to resuspend, transport or modify the deposit.

The impact of disposal control was further emphasized by moving the disposal point to the southeast for the President Roads operation. Because a taut-wire mooring was used for scows while Loran-C navigation was used for the hopper dredge with a requirement for stopping at the buoy, the distribution of material resulting from the President Roads operation was substantially smaller than previous ones, even though the hopper dredge would be expected to create a wider spread of material due to the high water content of its dredged material. It is readily apparent that the distribution of material to the east and south of the disposal point, particularly in terms of the coarse microtopography indicative of specific disposal points, was significantly less than on previous operations.

Additional information on sediment characteristics at FADS was obtained through REMOTS technology. Although REMOTS technology provides information on both physical and biological seafloor processes, only the physical/sedimentological data are discussed here. The results of the REMOTS photographic surveys support the sediment distribution pattern inferred from side scan sonar survey.

A map of the major mode of grain-size, based on the June 1985 REMOTS survey is given in Figure I.2-40. A sharp gradient exists between those stations in the northeastern region of the FADS and those located in the rest of the site. All stations to the west and south consist of silt-clay sediments.

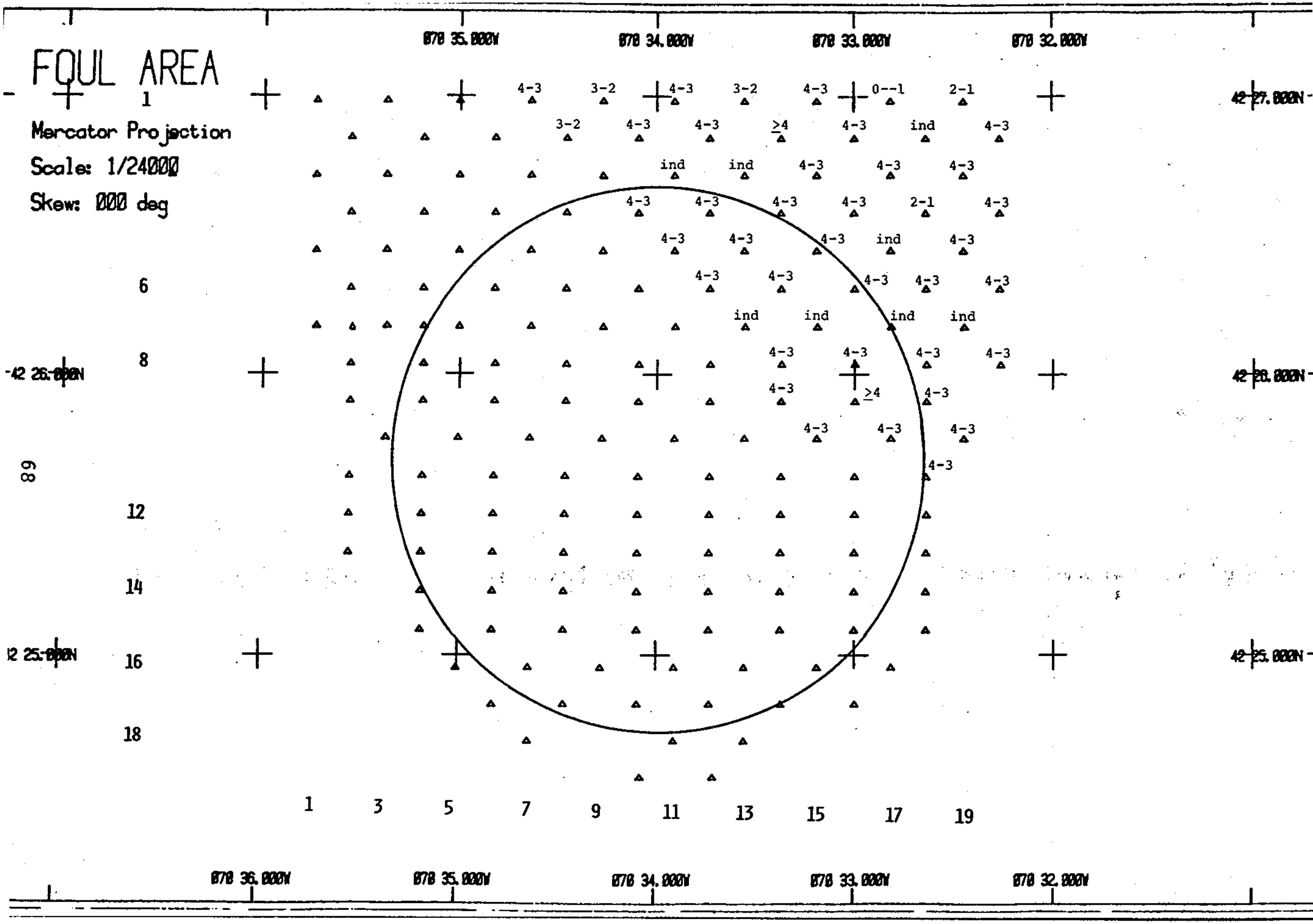


Figure I.2-40. Major mode of grain-size (o units) at FADS, June 1985.
(All unmarked sample locations were >4 o).

Those to the north and east consist of coarser sediments ranging from very fine sand (4-3 phi) to gravel (0 to -1 phi). Sediments at these coarse bottom stations are generally poorly sorted, with fine to medium sand lying over coarser material. There are relict bedforms in this area, apparently stabilized by dense mats of polychaete tubes (Figure I.2-41). The construction of dense polychaete tube fields may have caused the sedimentation and retention of fine-grained particles.

Figures I.2-42 a, b and c show the distribution of dredged material observed at FADS from June 1985 through February 1986. The presence of dredged material is indicated in REMOTS images by the following features: sand layers in an otherwise homogeneous mud facies, the presence of buried mud clasts, mottled sedimentary fabrics, or the presence of "relict" (i.e. buried) redox layers (Figure I.2-43). Dredged material is evident throughout the western portion of the surveyed area.

It is important to note that the REMOTS technique is capable of detecting dredged material for a longer period of time after disposal than side scan sonar. The primary reason for this is that the sediment surface returns to a natural condition in terms of acoustic reflectivity long before the sediment beneath the surface is fully oxidized.

In the fall of 1985, several stations to the west of the designated disposal area also exhibit evidence of dredged material. These stations fall within the boundaries of the historical disposal site adjacent to the present site. These images revealed no evidence of recent disposal activity (i.e., within the last six months) at any of these stations. The material observed appeared to represent relict sediments from past disposal activities (greater than 5 cm below the sediment-water interface).

A portion of the February 1986 REMOTS survey was concentrated around the new disposal buoy location at FADS. A cross of 26 stations spaced at intervals 100m was centered on this site. The results of the REMOTS survey centered on the new disposal site are shown in Figure I.2-44. The dredged material mound extends approximately 400 meters in all directions. To the east and south, the outermost stations do not show evidence of dredge material. To the north, the dredged material mound apparently overlaps with sediments from past disposal activity. To the west, apparent patches of dredged material are evident as far as 600 meters from the center of the site. Also, at station 250SW (i.e. grid station 16-9), a thick layer of dredged material is evident (greater than 17 cm). Because the lateral spread of dredged material extending from the disposal buoy is comparable with disposal mounds in Long Island Sound (i.e., approximately 400-500 meter radius), these observations suggest that good navigational control of dredged material disposal at FADS would allow successful capping operations.

Figure I.2-41 A REMOTS image from FADS station 1-15 showing a dense mat of polychaete tubes overlying coarse sediments. This bottom type is characteristic of the northeast corner of the FADS area. Scale = 1X.

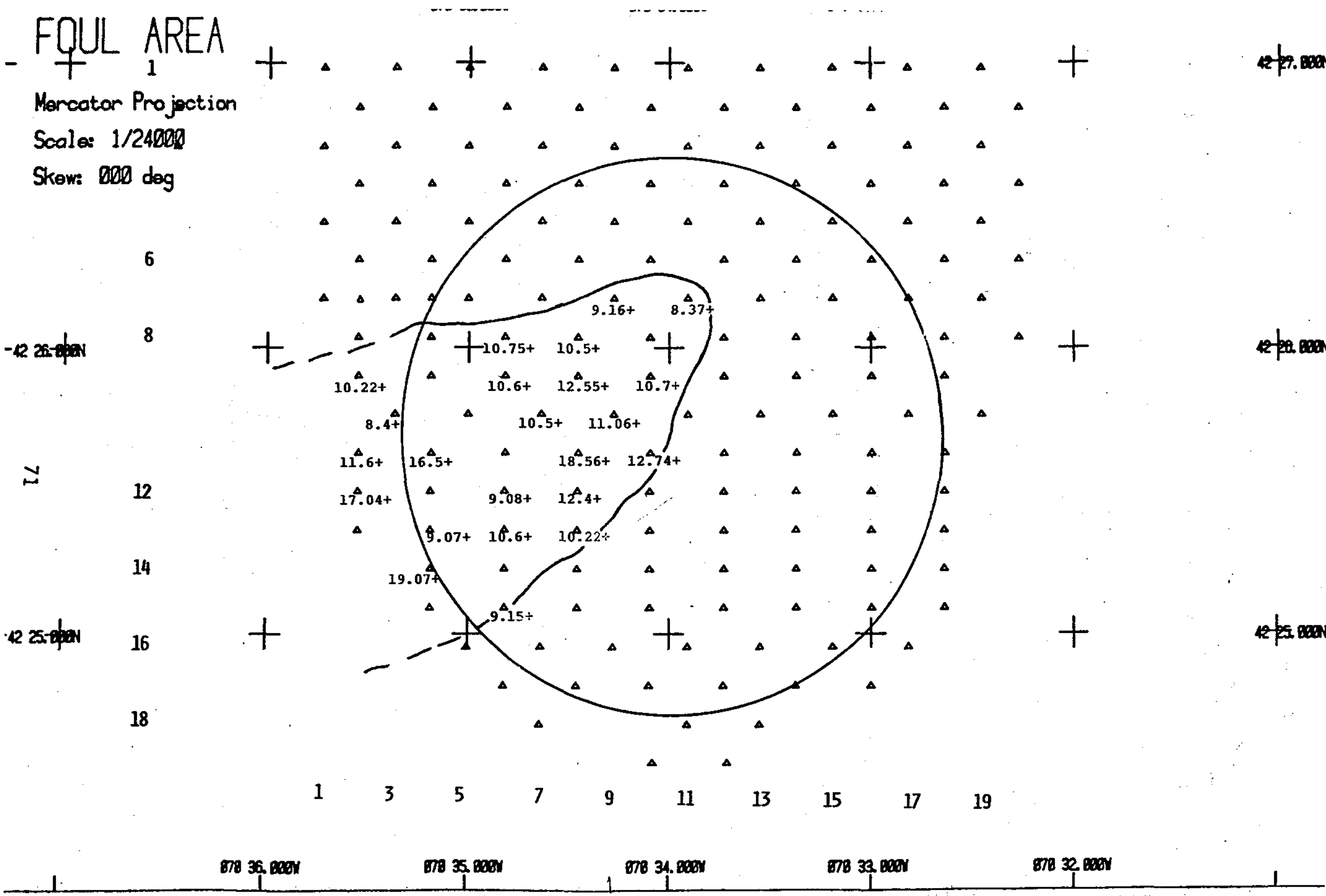


Figure I.2-42a The apparent distribution and thickness (cm) of dredged material at FADS in June 1985, based on the REMOTS survey. The + indicates that dredged material was thicker than the REMOTS prism penetration depth. The contour

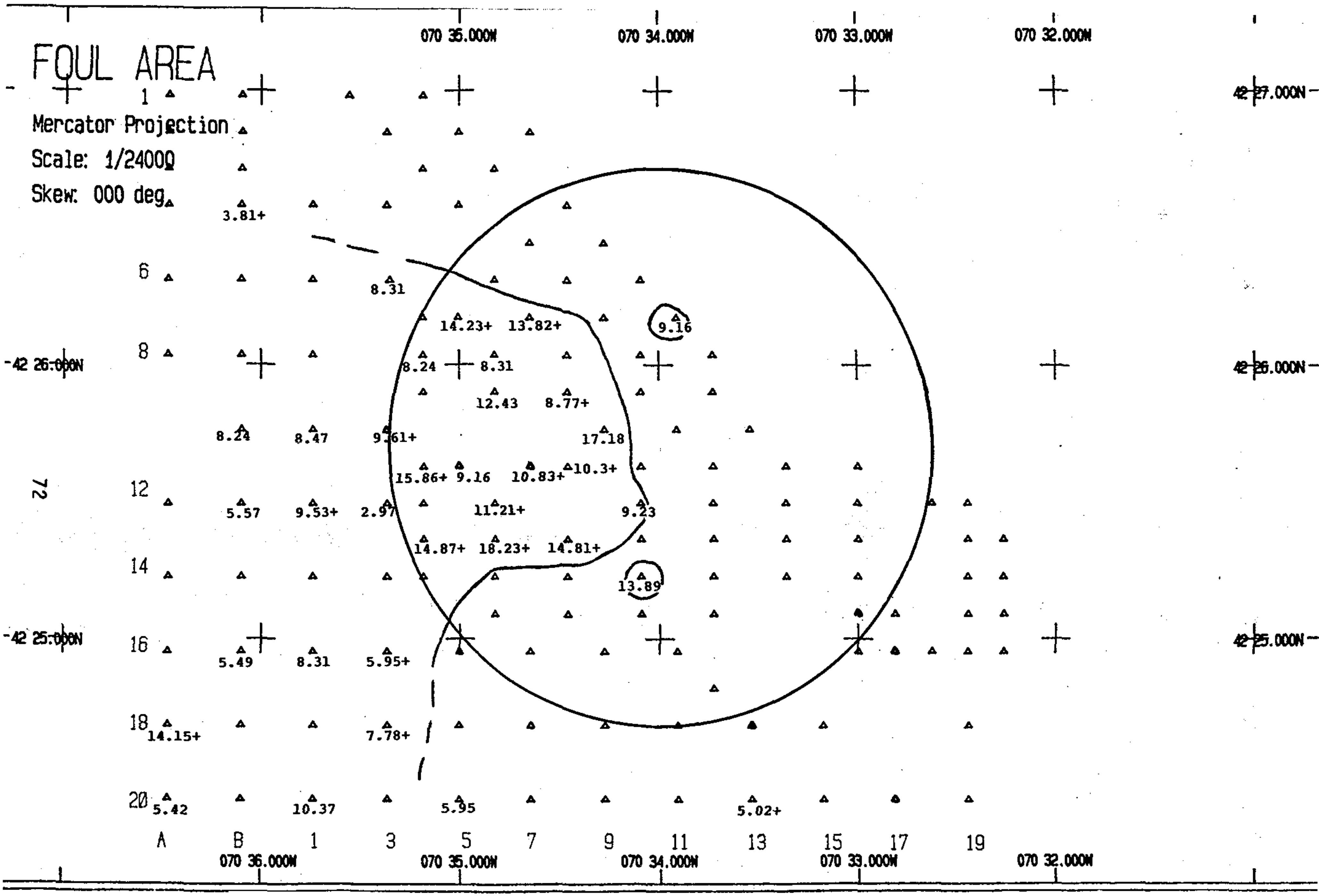


Figure I.2-42b The apparent distribution and thickness (cm) of dredged material at FADS in September 1985, based on the REMOTS survey. The + indicates that dredged material was thicker than the REMOTS prism penetration depth. The contour delimits the region with dredged material.

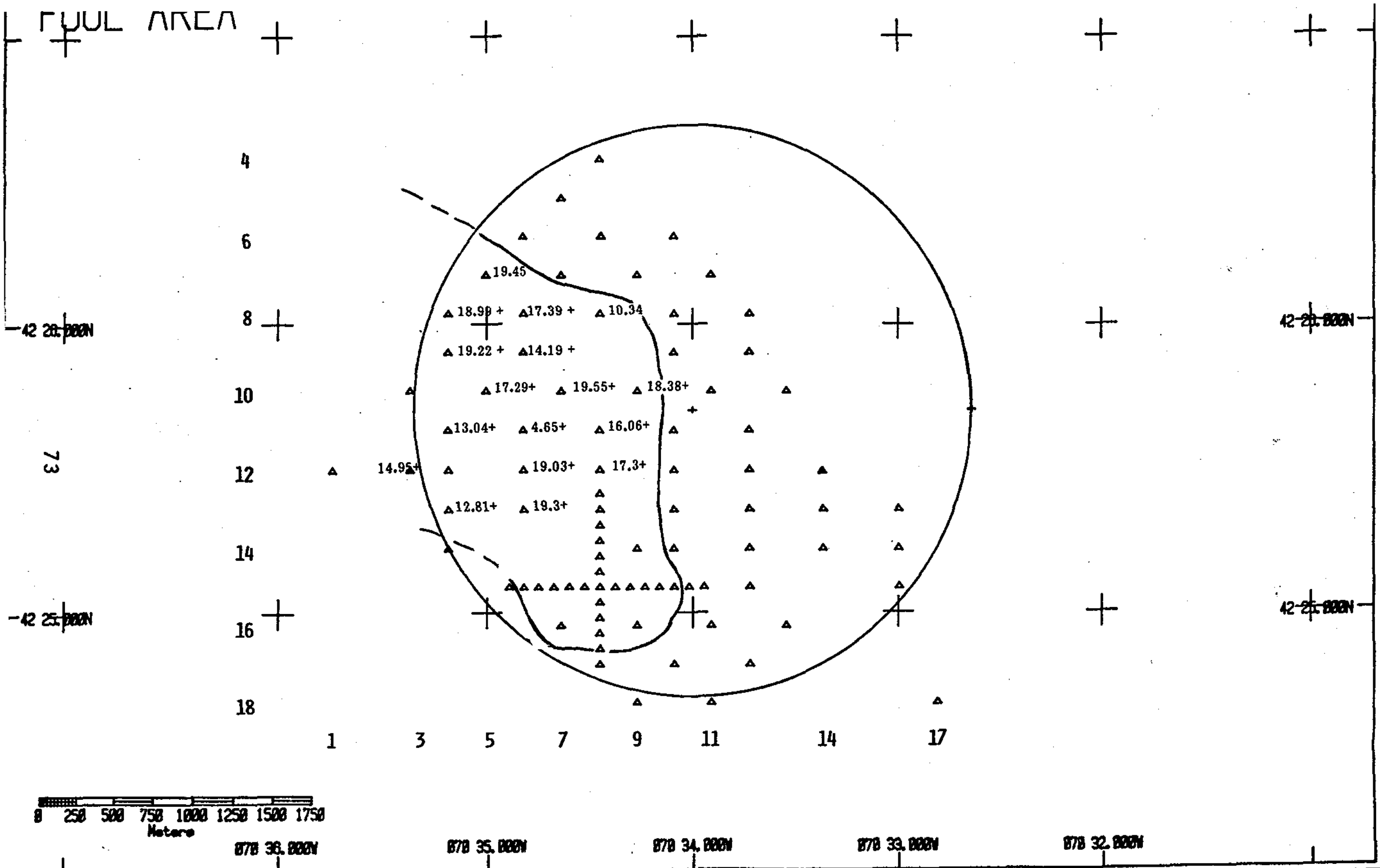


Figure I.2-42c The apparent distribution and thickness (cm) of dredged material at FADS in February 1986, based on the REMOTS survey. The + indicates that dredged material was thicker than the REMOTS prism penetration depth. See Figure I. 2-44 for the distribution of material in the region of "DGD" buoy (the sample cross).

Figure I.2-43 REMOTS image from the fall 1985 FADS survey (station 11-07) showing evidence of dredged material: the extremely low-reflectance (black) material at depth and the high-reflectance patches (arrows) which may represent deposited fish gurry.

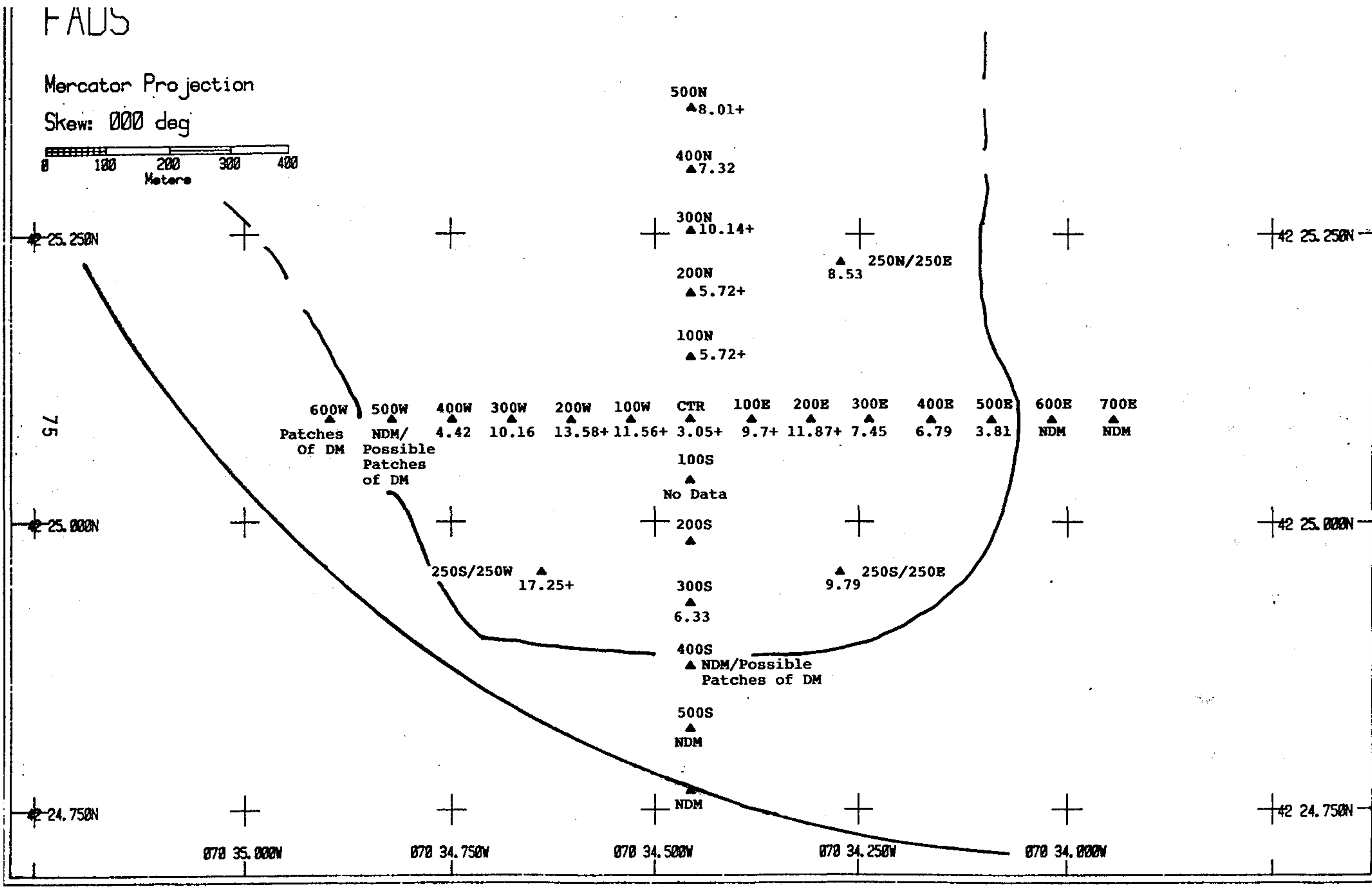


Figure I.2-44. The distribution of thickness (cm) of dredged material in the vicinity of the "DGD" disposal buoy in February 1986. A + indicates the dredged material is thicker than the REMOTS prism penetration. DM = dredged material, NDM = no dredged material

II. ENVIRONMENTAL CONSEQUENCES

As a result of previous work in the region and recent studies conducted at the Foul Area Disposal Site the environmental consequences of dredged material disposal and the interaction of the disposal operation with the physical environment can be well defined for this site. The following sections provide interpretation of data presented in previous sections as well as additional information to address the observed and expected effects of disposal at the Foul Area.

II.1 Short-term Effects

Short term effects are defined primarily as those which may occur during and immediately after disposal of dredged material and include such parameters as plume formation, convective descent, bottom deposition and initial dispersal of material. Although disposal of dredged material has taken place in the vicinity of the Foul Area for a number of years, control and monitoring of the disposal operation has only recently been accomplished. Consequently, the most pertinent data on the short term effects of disposal are available through studies conducted by the New England Division as part of the DAMOS program during 1982 and 1983.

II.1.1 Disposal Processes

During the fall and winter of 1982-83, a major dredging project was conducted over a large portion of Boston Harbor, and the material was dumped at the Foul Area. The material was dredged using a clamshell bucket from the Chelsea and Mystic Rivers in Boston and transported to the disposal site using large scows. Upon completion of the inner harbor work, a second project in President Roads was dredged using the hopper dredge SUGAR ISLAND. The material from this project was deposited with the hopper dredge under Loran-C control.

In order to obtain a consensus as to the suitability of dredging and disposing of silt with a hopper dredge in the New England region, a study comparing the results of hopper versus scow disposal operations was jointly funded by Great Lakes Dredge and Dock Co. and the New England Division of the U.S. Army Corps of Engineers (SAI, 1984). Studies of the scow disposal operations were conducted during the summer and fall of 1982. Observations of the hopper dredge disposal took place during January 1983, and a post-disposal monitoring survey was conducted in April 1983. Plans for repetitive measurements on a number of hopper dumping events were not fully executed because the SUGAR ISLAND was ordered to a different location for an emergency operation. Sufficient data were obtained, however, to provide a meaningful comparison between the two techniques.

Disposal of dredged material from the clamshell scow operation took place at a taut-wire moored buoy located approximately 200 m east of the Coast Guard "A" buoy marking the disposal point normally used. Bathymetric and sediment surveys were made over the area surrounding this location to obtain baseline information for assessing changes resulting from the disposal operation.

Depth measurements of an 800 x 800 m area surrounding the disposal point indicated a gently sloping bottom from approximately 90 m on the northern margin into a circular depression with a maximum depth of 93.5 m in the southern portion of the survey area. Sediments from the area consisted of oxidized silts supporting a diverse and mature infaunal community. Analysis of heavy metal content of sediments indicated a fairly homogeneous distribution of metals with slightly higher values of lead, zinc, mercury and copper in the vicinity of the disposal buoy.

Following disposal of Boston Harbor sediments during the summer of 1982, replicate surveys of the disposal site were conducted in September and October to assess the results of disposal operations. The resulting contour charts did not indicate formation of a disposal mound.

However, side scan surveys of the area did reveal a series of dark, high reflectance areas in a pattern extending from NW to SE across the site. These high reflectance zones have been seen in other disposal sites and are generally indicative of recently deposited dredged material. Samples taken from the locations of these zones support such a conclusion.

Bulk sediment chemistry data from samples obtained in October, 1982 are presented in Table II.1-1. These data, taken from locations in the vicinity of the disposal site, and from areas northwest of the designated disposal point, all have elevated levels of heavy metals in comparison to the Reference Station which was located on natural sediment east of FADS. Furthermore, descriptions of these samples indicated a distribution of dredged material extending to distances of more than 700 meters to the north as well as concentrations of gravel and cohesive clay nodules at distances of 500 meters north and northwest of the buoy.

From this information it is apparent that point dumping was not successfully accomplished on this project and that the formation of a disposal mound was impossible under these conditions. Observations of disposal operations made from the research vessel confirmed that the scows approached the disposal buoy from the northwest, were towed to the disposal point on a long tether, that the tugs rarely stopped at the disposal point, and that disposal frequently occurred when the tug was abeam of the buoy rather than the scow. Consequently, the deposit created had an elliptical shape oriented from northwest to southeast

Table II.1-1

Results of Chemical Analysis - Foul Area Disposal Site
October 1982 Cruise
North-South

Location	% Volatile Solids NED	ppm O&G	ppm Hg	ppm As	ppm Pb	ppm Cr	ppm Cu	ppm Zn
700N	5.58	3,610	0.14	10.0	184	159	105	380
500N	3.70	4,140	0.32	11.0	227	126	137	604
300N	1.76	1,840	0.30	5.2	124	209	72	271
CTR	2.77	2,800	0.20	4.0	84	157	60	212
300S	4.60	3,430	0.53	14.0	210	130	135	608
500S	4.48	1,040	0.12	8.9	90	74	58	190
BL4	3.25	3,900	0.61	11.9	179	186	117	287
NW#1	5.84	5,200	0.64	6.4	233	201	157	402
NW#2	5.23	5,800	0.56	*	246	161	155	409
NW#3	4.53	5,000	0.69	14.8	212	176	137	367
$\bar{x}$	4.17	3676.00	0.41	9.58	178.90	158.80	113.30	373.00
σ	1.30	1490.86	0.22	3.80	59.40	39.45	37.90	144.54
REF	4.49	171	*	89	48	54	18	143

without significant accumulation of material at any specific point.

This procedure is in sharp contrast to the disposal of material at Portland, Maine which also took place in open water, 60 meters deep, with a disposal buoy. In this case the tow line was shortened prior to disposal, scows were stopped immediately adjacent to the disposal buoy and a significant mound was created.

It is apparent that more careful control of the disposal operation is required to create a mound in the water depths of 90 meters encountered at the Foul Area. Such control should now be possible since the New England Division has initiated a Disposal Inspector Program which is closely tied to the overall Dredged Material Disposal Management and Monitoring Program currently underway through the Regulatory Branch of NED. Under this program, NED inspectors who are fully aware of the disposal management procedures required for point dumping will be aboard the tug on every disposal operation conducted at FADS to insure that controlled disposal will occur in the future.

The success of this procedure was demonstrated by recent disposal activities at FADS conducted during the fall and winter of 1985-86. As described in Section I.2.4, disposal of dredged material at the buoy installed in the southern portion of the site resulted in a small mound with a lateral extent of approximately 400 meters. This distribution is similar to that observed on point disposal operations in much shallower water in Long Island Sound.

Observations of the disposal of dredged material by the hopper dredge SUGAR ISLAND were conducted on 1 February 1983, on the last operation prior to departure for emergency service in Florida. The major questions raised relative to the use of a hopper dredge for projects in the New England area centered around the behavior of silt material during disposal. Previous experience had shown that, in general, silts dredged by a clamshell/scow operation were immediately transported to the bottom in a convective flow that produced a relatively small plume. A concern existed that the hopper dredge technique would add water to the silt and break down any cohesiveness in the sediment so that disposal would generate a large, slowly settling plume that might be transported for substantial distances.

Consequently, the emphasis of this program was placed on examination of plume behavior through a combination of acoustic tracking and in-situ sampling. The R/V EDGERTON was configured for tracking the plume with a dual channel (50 and 200 KHz) Acoustic Remote Sensing System manufactured by Datasonics Inc. and the SAIC precision navigation system utilizing a Del Norte Trisponder positioning system providing +/-2 meter accuracy.

The Datasonics Model DFS-2100 system provided simultaneous dual channel operation with high power output, low receiver noise levels and calibrated control of signal level which permits monitoring of extremely low concentrations of material in the water column, and acquisition of quantitative concentration levels when correlated with ground truth sampling. On this study, ground truth data were obtained from the M/V HUDSON RIVER, a support vessel supplied by Great Lakes Dredge & Dock Co. Samples of the water column were obtained during the plume tracking operation using Niskin bottles. The HUDSON RIVER was located in the plume by the EDGERTON and a messenger was dropped to trip the bottles. The salinity of each water sample was measured with a Beckman RS-7B induction salinometer and the concentration of material was determined by filtering an aliquot through a pre-weighed 0.4 micron nucleopore filter, and then weighing the filter and deposited material on a Mettler H-51 analytical balance.

Observations of the disposal plume created by the SUGAR ISLAND were conducted on 1 February at 1600 under relatively calm conditions. The EDGERTON positioned herself immediately astern of the dredge and moved over the disposal point as soon as dumping occurred. Figure II.1-1 indicates the track of the EDGERTON during the next hour and a half as she tracked the plume. The striped section of the chart indicates the spatial distribution of plume 15 minutes after disposal while the cross-hatched section shows the spatial distribution one hour later. During the 75 minute survey period, the maximum extent of dispersion was approximately 750 meters in a southeasterly direction. This represents a dispersal rate of 16 cm/sec or .3 knots.

Although this spatial distribution provides an indication of net transport, the acoustic records provided a much more detailed view of the plume dissipation. Immediately after disposal, the 50 KHz channel had substantially stronger reflections than the 200 KHz channel indicating that relatively coarse particles were in suspension. Furthermore, both channels indicated a narrow column of material extending from the surface to the bottom which rapidly expanded into a turbidity cloud in the lower portion of the water column. These phenomena strongly suggest that the material dumped by the hopper dredge acted in the same manner as material dumped from scows. The dredged material was transported to the bottom in a convective flow which, upon impact with the bottom, spread radially and deposited most of the material in a turbidity deposit within a few minutes of disposal.

This is also shown by the resulting dredged material deposit, as no indications of expansion of the existing distribution of dredged material was observed in sediment samples taken in April, 1983. Descriptions of samples indicated the presence of dredged material in the same locations as the October, 1982 samples, however, the heavy metal content of these

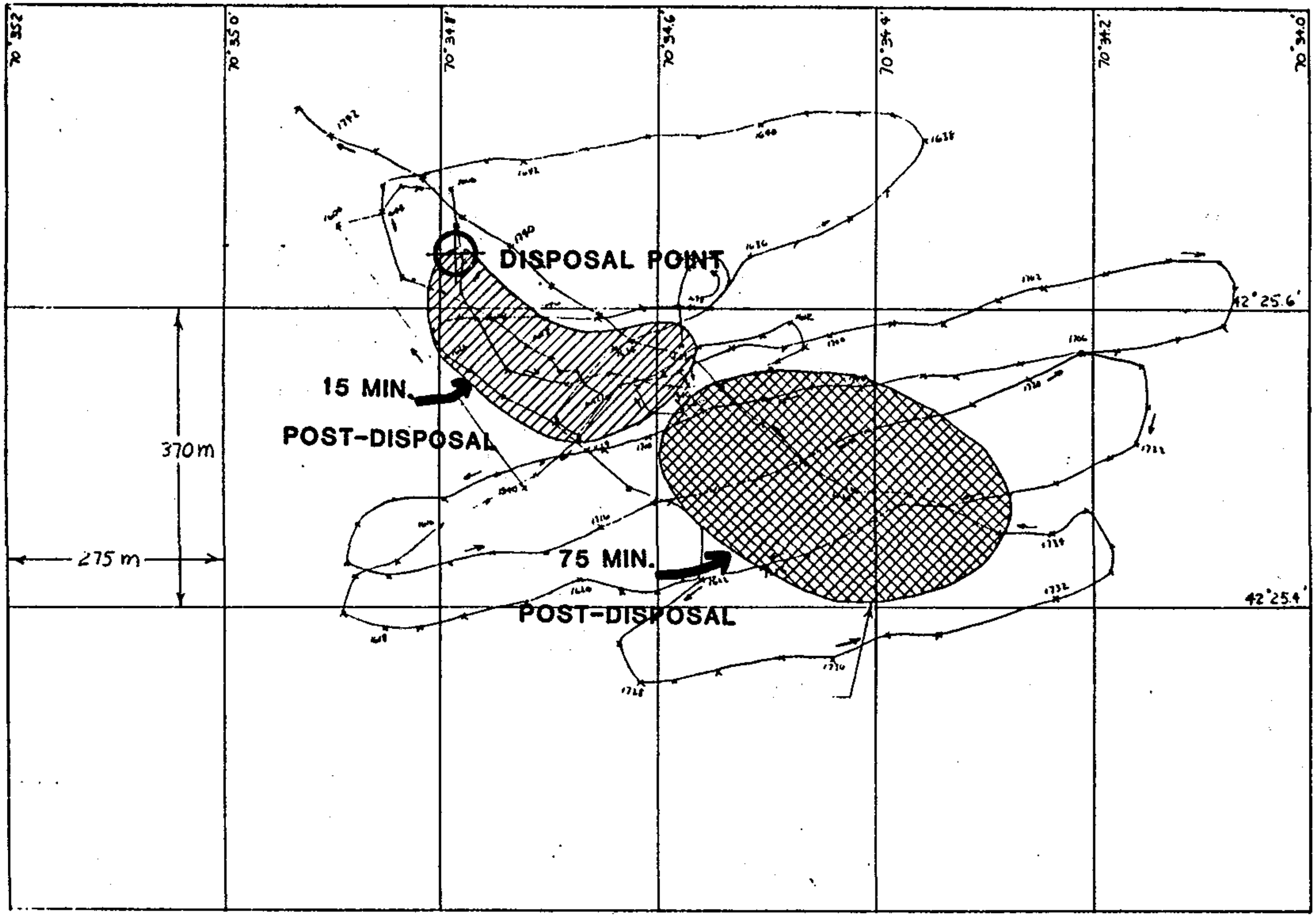


Figure II.1-1 Ships Track and Plume Dispersion following Disposal Operations Hopper Dredge SUGAR ISLAND February 1, 1983 sediments, presented in Table II.1-2, had reduced levels of contaminants in many cases, particularly in the vicinity of the disposal point. These reduced levels would be expected in material deposited by the hopper dredge as the sediment from President Roads in the outer harbor was substantially less contaminated than that dredged by clamshell/scow operations in the inner harbor. Although not intended to address the question of capping, in effect, the hopper dredged material is acting as a cap to the previously dumped material. However, since control of the hopper dredge disposal was much better than that of the scow operations a complete cap of the earlier material was not accomplished.

In summary, the recent experiences of disposal at the Foul Area Disposal Site indicate that navigation control of dumping is the most important factor affecting the short term effects caused by the disposal process. Both the hopper dredge and scow disposal operations result in similar deposits and if proper point dumping procedures are used it appears that deposits with dimensions similar to those developed in other areas can be created.

II.1.2 Fate of Discharged Material

The only measurements of the behavior of dredged material in the water column in the vicinity of FADS were made during the plume tracking associated with the monitoring of hopper dredge disposal described in the previous section. During this operation a concentration of 750 mg/l of sediment was observed in the upper layer of the plume immediately after disposal. This decreased rapidly to 39 mg/l within 20 minutes of disposal and to concentrations of approximately 5 mg/l after 40 minutes. In addition, the reflections from the 50 KHz channel had completely disappeared after 40 minutes indicating that only fine materials remained in suspension. Since the ambient concentration of suspended sediment in this region was on the order of 1 mg/l the plume did represent a detectable increase above background levels for a period of time. However, the displacement of the plume was so slow and the concentration of suspended material so low that the only discernable effect of the disposal operation should have been the creation of a deposit in the immediate vicinity of the disposal point.

Since the disposal took place in January, no thermocline was present to affect the dispersion of the disposed dredged material. Because most of the material was transported to the bottom as a convective flow, and the coarser particles settled out of the water column within 40 minutes of disposal; it is apparent that the density structure would only affect a small percentage of extremely fine materials remaining in suspension, and should not significantly alter the results of the disposal operation.

Table II.1-2

Results Of Chemical Analysis
North-South Transect Near 70°35'.00 - April 1983

Location	% Volatiles NED	ppm Oil & Grease	ppm Cr	ppm Zn	ppm Cu	ppm As
1000N-150W	1.51	757	55	233	35	14.5
500N-150W	4.20	2,740	208	327	133	7.6
100N-350W	4.00	1,780	225	260	100	6.5
400W	2.22	6,510	444	469	114	10.2
275W	3.36	1,830	225	266	100	5.4
150W	4.39	1,840	176	168	81	5.2
CTR	1.65	158	38	92	17	50.0
250S-400W	4.10	4,210	241	424	147	14.0
250S-150W	3.28	2,550	216	301	106	6.0
500S-150W	2.69	3,670	188	525	106	25.6
1000S-150W	4.09	610	81	292	46	11.1
$\bar{x}$	3.21	2453.75	192.67	303.50	90.42	13.49
σ	1.01	1757.83	106.39	121.87	39.14	12.90

To date disposal induced short-term changes to the bottom topography at FADS have been minimal for two reasons: first the control of disposal has been poor and material has been spread over a large area, and second, the amount of material that has been deposited under careful control has always been relatively small (on the order of 100,000 m^3) and not sufficient to generate a significant topographic feature. Based on recent results which indicate a spread of material similar to shallow dredged material deposits, future controlled disposal operations may in fact create broad topographic features with several meters vertical extent.

II.2. Long-Term Effects

The bathymetry of the Foul Area Disposal Site as described in Section I.2.3 is characterized by gently sloping bottoms indicative of a depositional basin except in the northeast quadrant where the glacially derived shoals create sharp topographic discontinuities. Deposition of dredged material into this environment has not yet created any topographic features; however, future operations could create small, broad disposal mounds several hundred meters in diameter and several meters high. Because the site is located in an open basin, these deposits would have minimal effect on the physical conditions at the site and would certainly not affect the overall circulation in the area.

II.2.3 Potential for Resuspension and Transport

The long term dispersion of dredged material through resuspension and transport is a critical factor for selection of a disposal site in New England since containment of the dredged material within the site is one of the primary objectives of the disposal management program. Two factors of major importance in terms of long term dispersion are the physical processes affecting the sediments and the biological reworking of those deposits which may cause vertical and horizontal redistribution of contaminants.

<u>Physical Processes</u>

The physical processes affecting the deposited dredged material were discussed in detail in Section I.2.2. These data all indicate that under most conditions neither tidal nor non-tidal processes have sufficient energy to erode and transport sediment at this disposal site. In fact, the site is in an area where sediment accumulation is occurring rather than erosion. However, there are certain instances where some resuspension of material can occur, particularly in the presence of large northeast storm events. Data indicate that these storms are rare; occurring on the order of once every ten years. During these storms, the bottom currents in the vicinity of FADS flow in a southeasterly direction in response to the build-up of sea level on the nearby coast. Therefore, if resuspension were to occur as a result of these storm events, transport of material would be toward the deeper areas of the Stellwagen Basin were redeposition would most likely take place. When such resuspension takes place, not only the dredged material, but the entire bottom is resuspended and the amount of dredged material relative to other sediment sources in the area would be minuscule. Consequently, it is doubtful that significant concentrations of dredged material could ever be detected beyond the margins of the disposal site.

Bioturbation

The eventual recolonization of the dredged material by deposit feeding infauna will affect the sediment mass properties (bed roughness, porosity, shear strength, water content, etc.) that can have a significant effect on the potential for resuspension and transport (Rhoads & Boyer, 1982). If burrowing organisms are relatively active, a few individuals per unit area of bottom, can have a major impact on remolding and dilating fine grained sediment. Figure II.2-1 is a REMOTS image from FADS in which the effects of bioturbation on sediment texture are readily apparent. Sediments such as these are more susceptible to erosion and transport than freshly deposited, cohesive dredged material that is either azoic or inhabited only by small tubicolous, opportunistic polychaetes characteristic of initial colonizing benthos. The intensive particle bioturbation characteristic of these mature, equilibrium communities is associated with fine grained sediments with water contents greater than 60% and commonly over 70%. The geotechnical properties and transport dynamics of fine-grained sediments change seasonally and spatially with the highest probability of transport occurring when the water temperatures are highest and bioturbational activities are at their peak. However, it is important to note that bottom temperatures at FADS do not vary significantly over the year and that periods of highest temperature are least likely to have strong storm events which would create easterly winds. Therefore, the effects of bioturbation should be smaller and less variable over the seasons than in more shallow sites.

Summary of Physical Effects

The Foul Area Disposal Site meets all of the requirements for a disposal site capable of containing dredged material within its boundaries. The site is located in a depositional basin in Massachusetts Bay, and because of the low currents and deep water can be expected to accumulate sediment over a period of time. As with all locations, there is a certain potential for sediment movement, which in this area would be associated with rare, intense northeasterly storm events, which could move sediments in a southeasterly direction. However, the impact of such an occurrence would be minimal and undetectable beyond the margins of the site due to dilution of dredged material with natural sediments.

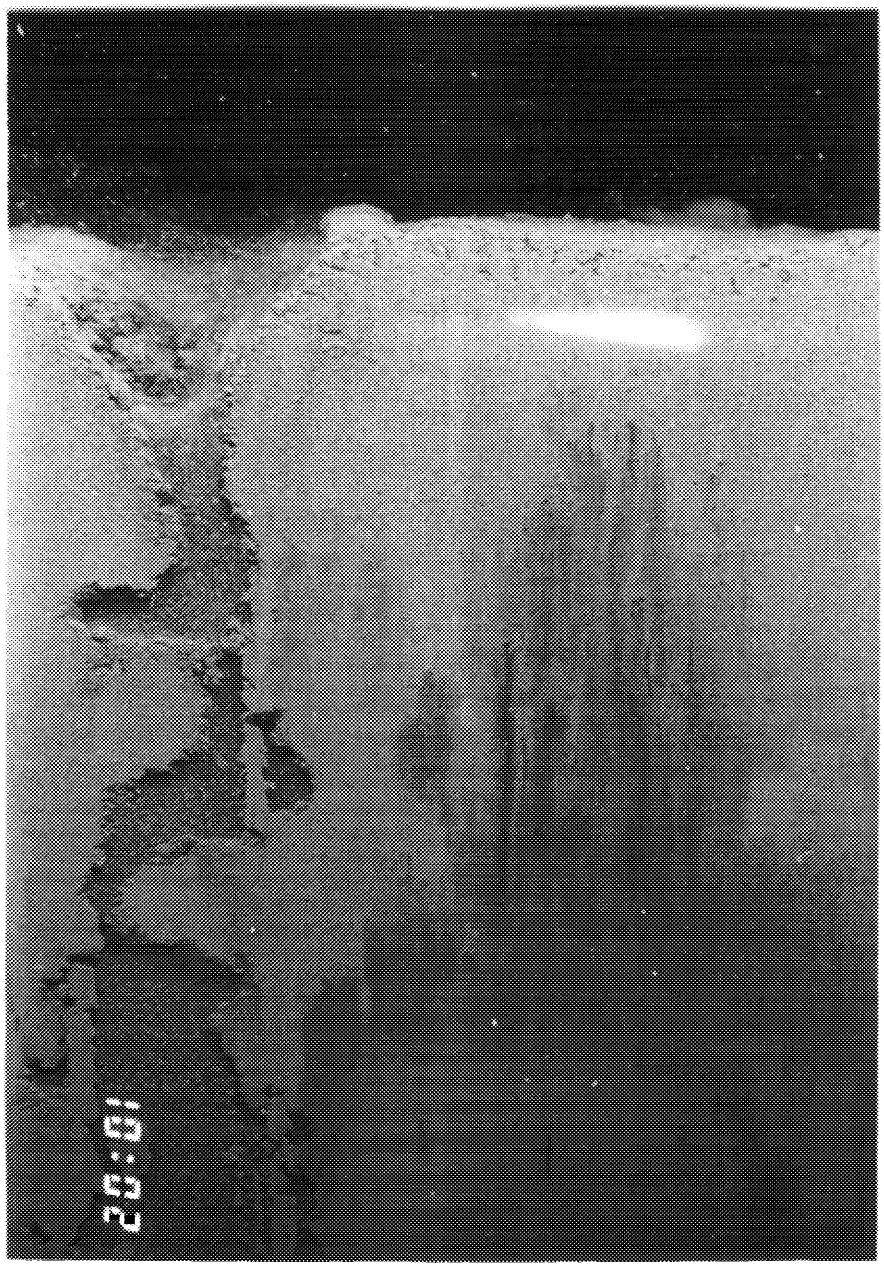


Figure II.2-1 REMOTS image from FADS outside the disposal area (northwest corner of the sampling grid). This area is colonized by Stage III deposit-feeding infauna which actively bioturbate the top 10-15 cm of sediment, affecting the geo-technical mass properties of this upper sedimentary layer. Scale = 1X.

The tidal currents at the site are not sufficient to resuspend dredged material and evidence from disposal operations has shown that material deposited at the site reaches the bottom as a cohesive mass through convective descent from the disposal vessel. Consequently, it can be expected that deposits of dredged material can be developed which will remain stable within the site over the long-term. Such a conclusion has been demonstrated by the continual presence of dredged material throughout the west central portion of the site which was derived from previous disposal operations.

The most important factor affecting the distribution of dredged material at the site appears to be the disposal control exercised by the dredging contractor. Previous disposal operations did not attempt to point dump material and the resulting deposits cover a relatively large area. Recent operations, using taut wire moored buoys have been more successful in containing the spread of material and have produced deposits similar to those generated at other disposal sites in New England.

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APPENDIX

LIST OF TABLES

LIST OF FIGURES

June 6, 1985
Buoy "A"

42° 25.671N
70° 35.004W

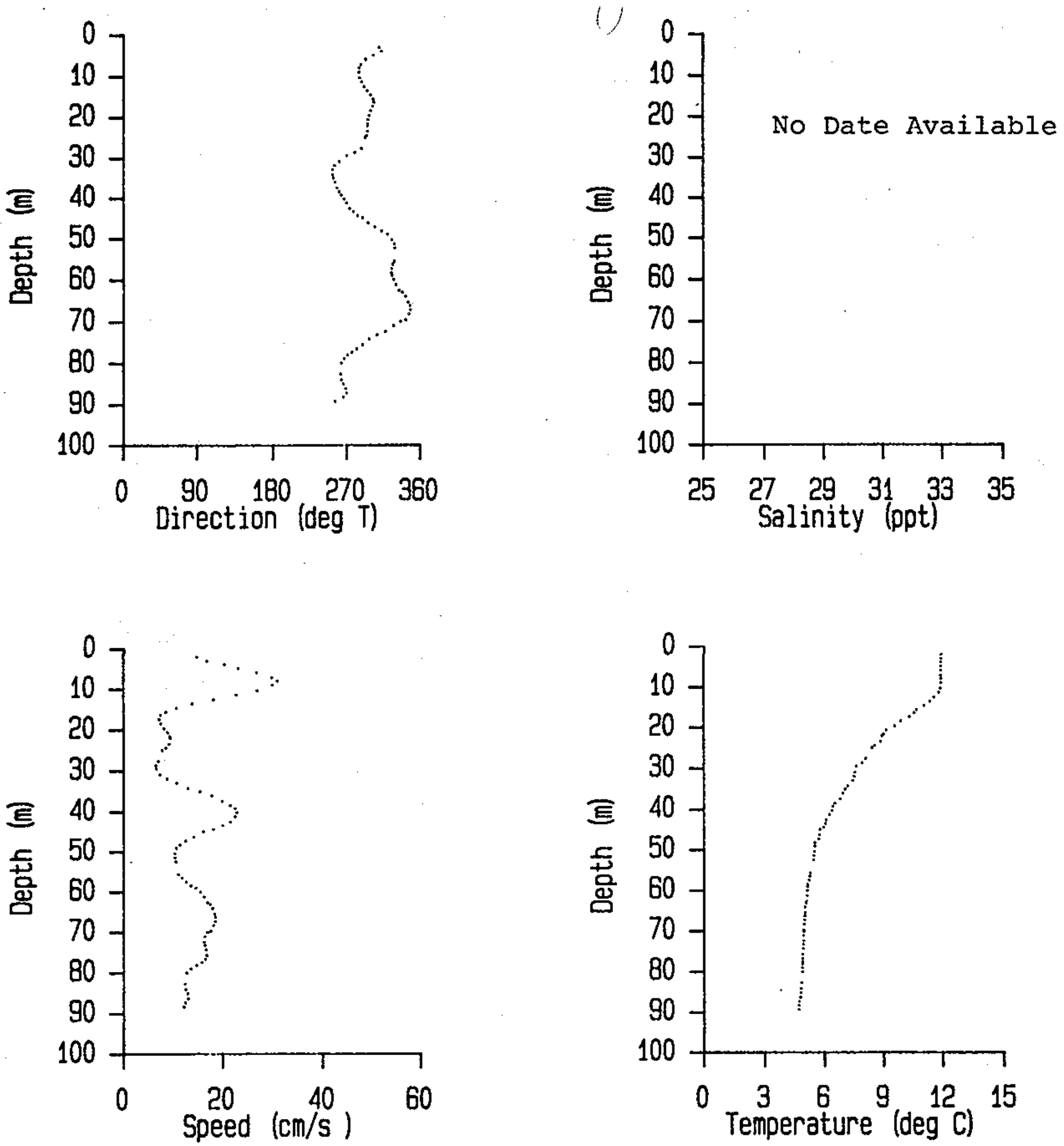


Figure I-1 Results of direct reading current meter casts at the Foul Area Disposal Site.

July 2, 1985

42° 25.647N
70° 34.413W

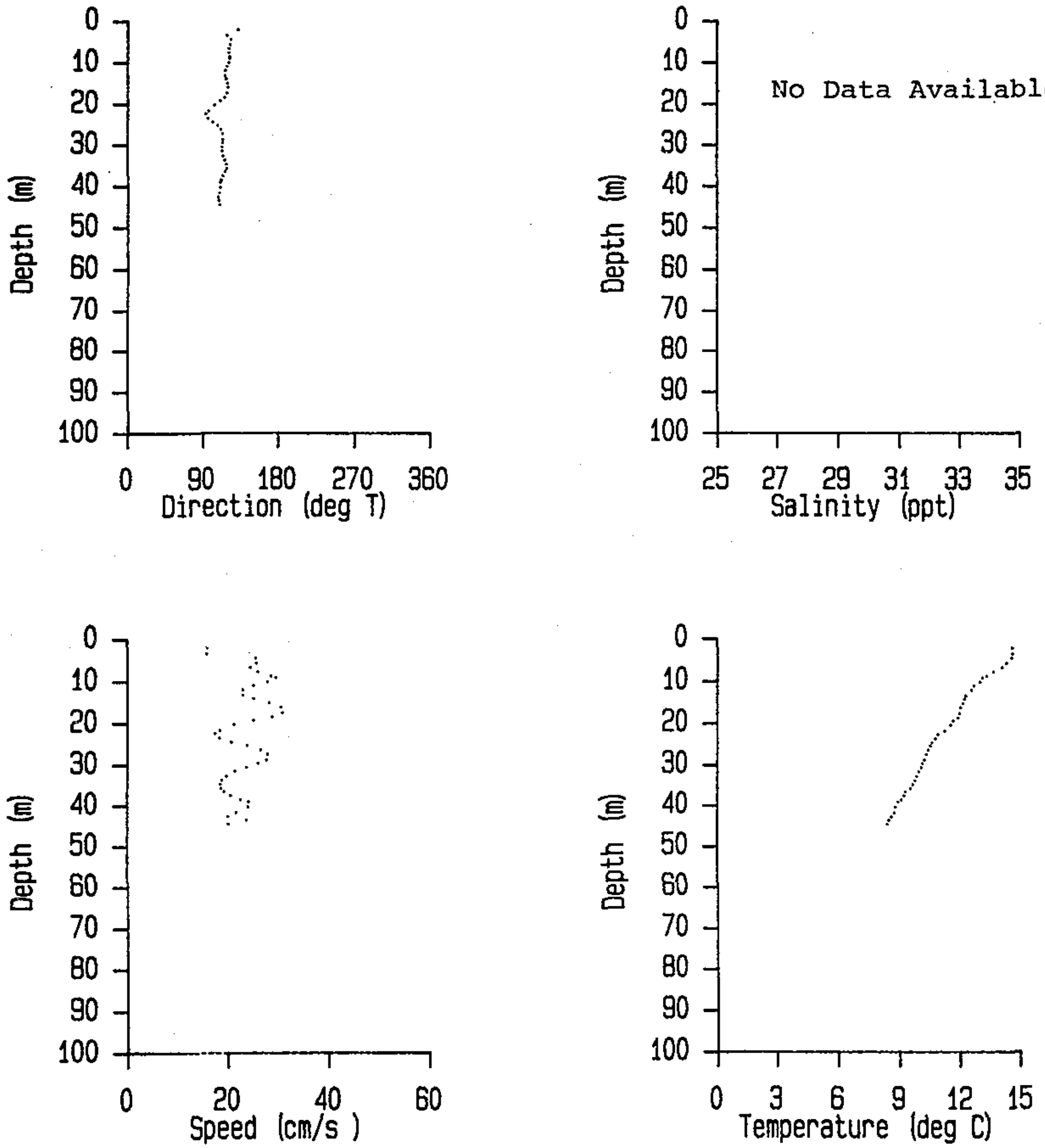
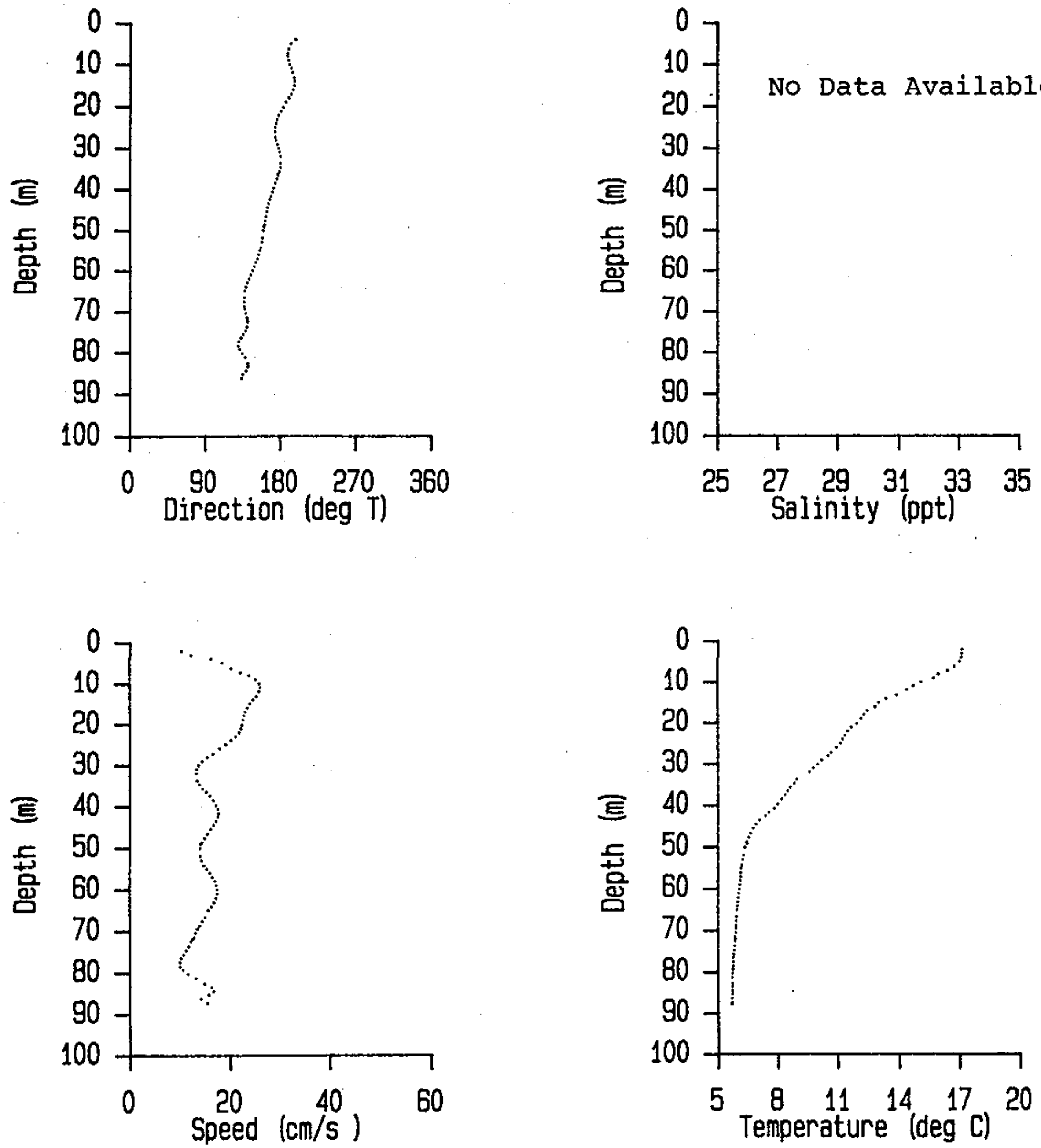


Figure I-1 continued



August 6, 1985
Buoy "A"

42° 25.671N
70° 35.004W

Figure I-1 continued

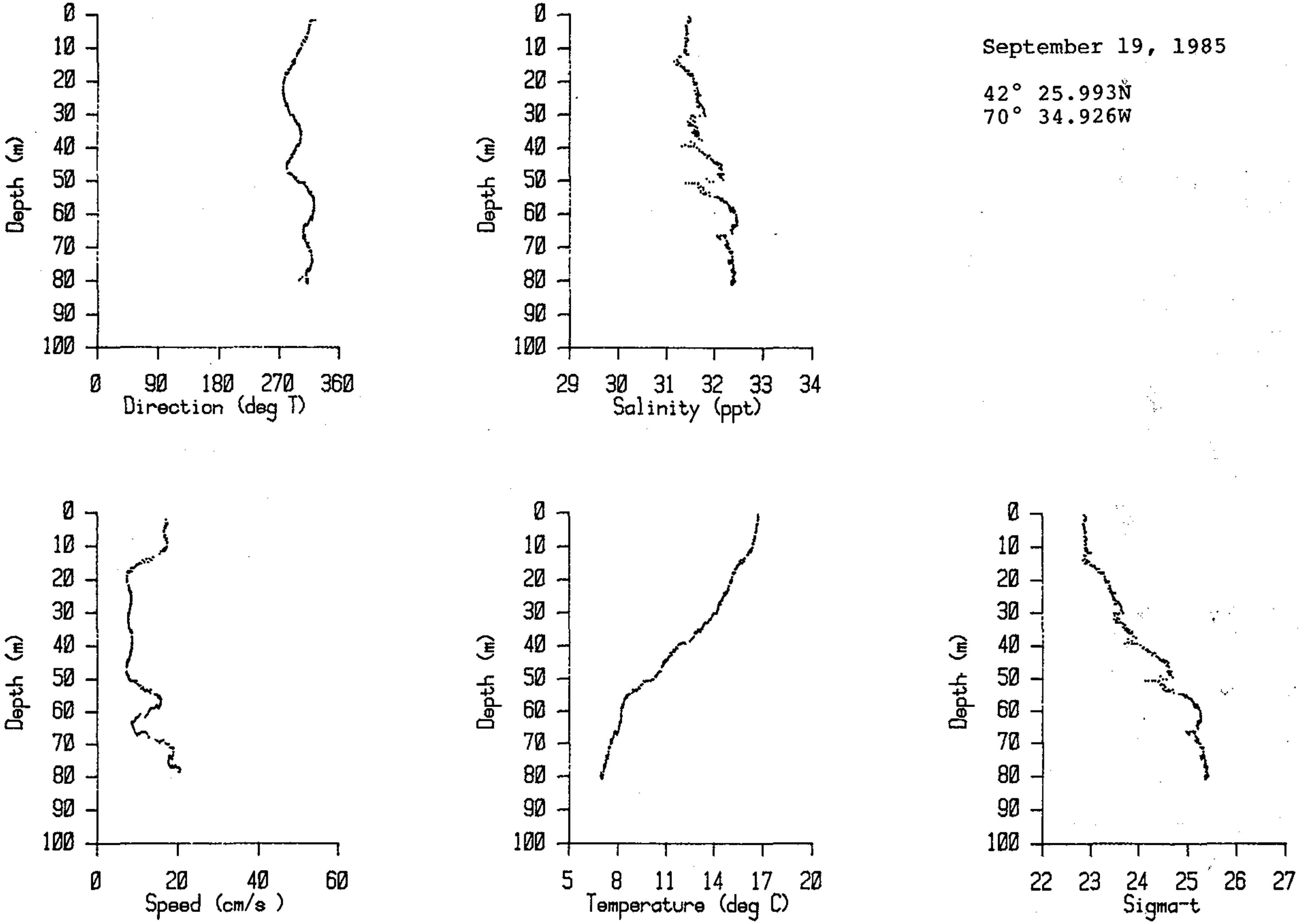


Figure I-1 continued

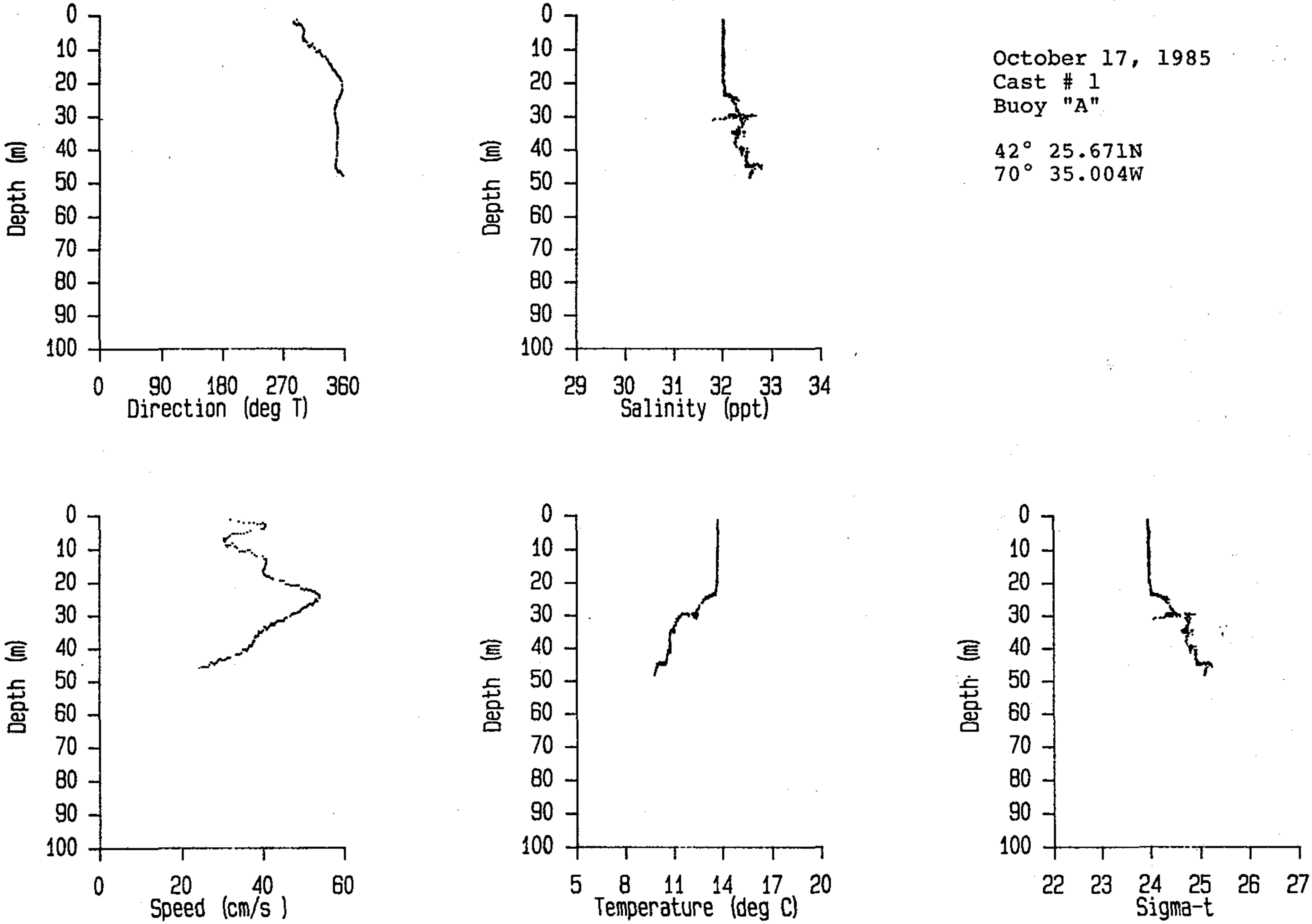


Figure I-1 continued

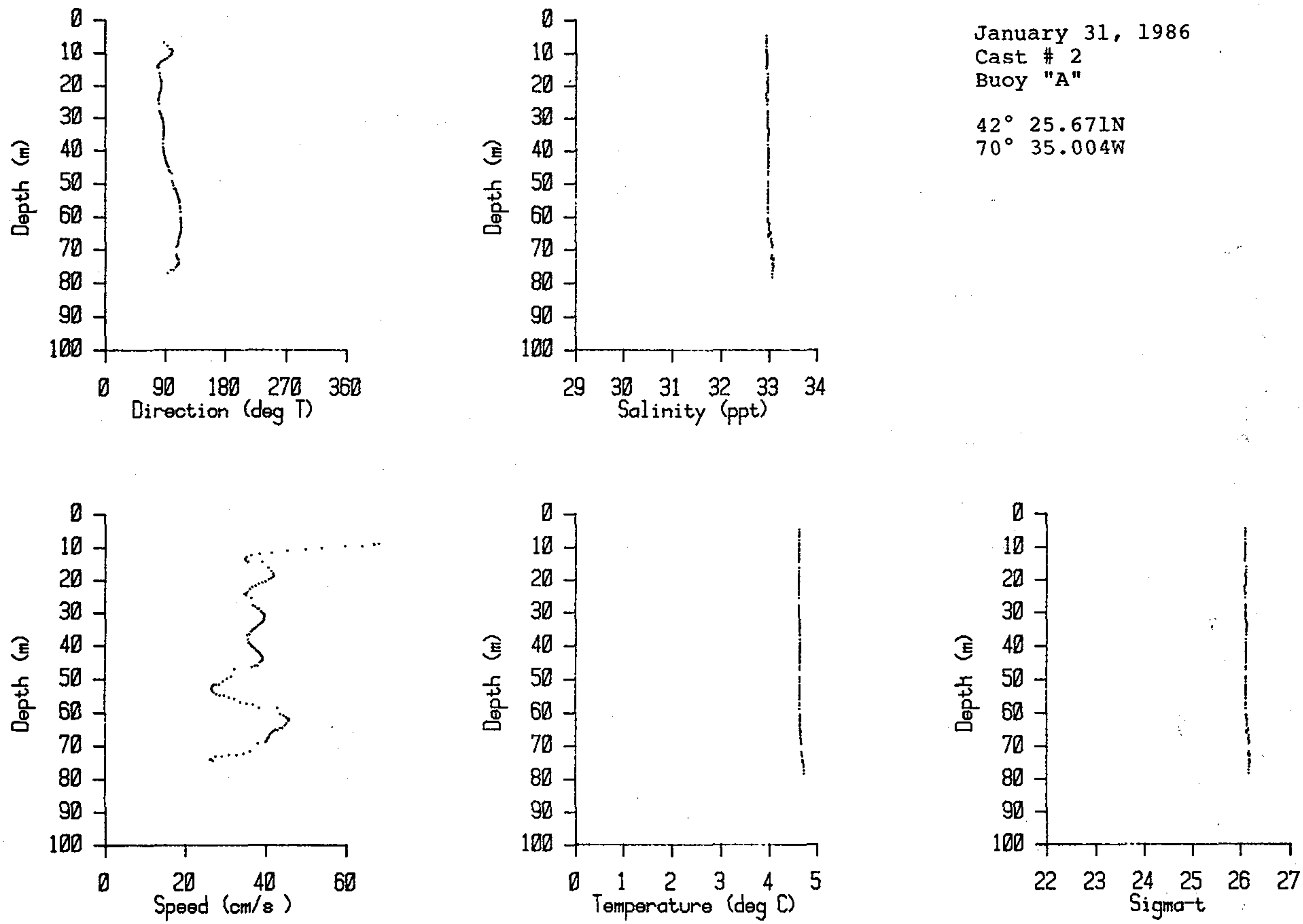


Figure I-1 continued

January 31, 1986
Cast # 3
Buoy "A"

42° 25.671N
70° 35.004W

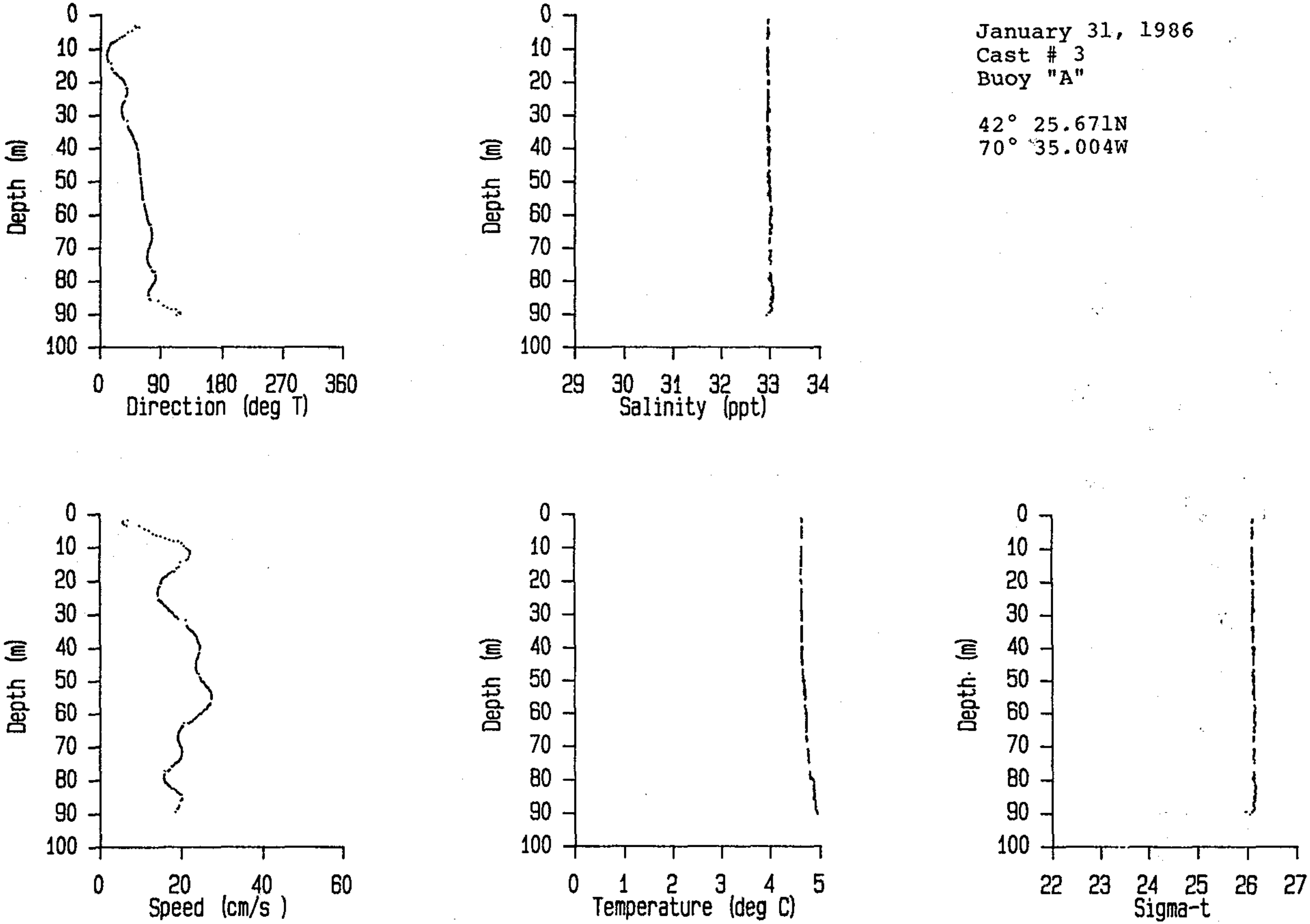


Figure I-1 continued

January 31, 1986
Cast # 4
Buoy "A"

42° 25.671N
70° 35.004W

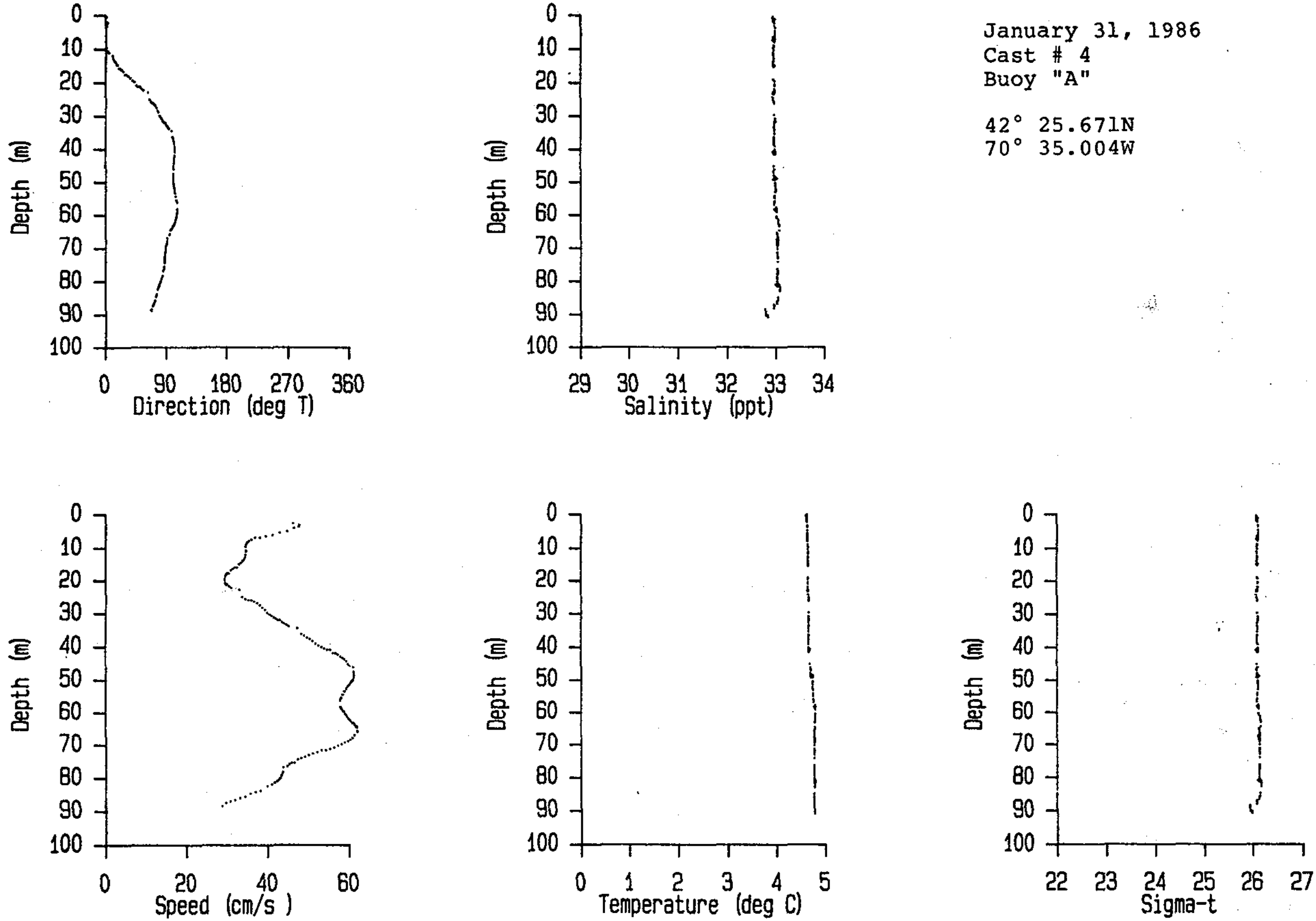


Figure I-1 continued

February 1, 1986
Cast # 5
Buoy "A"

42° 25.671N
70° 35.004W

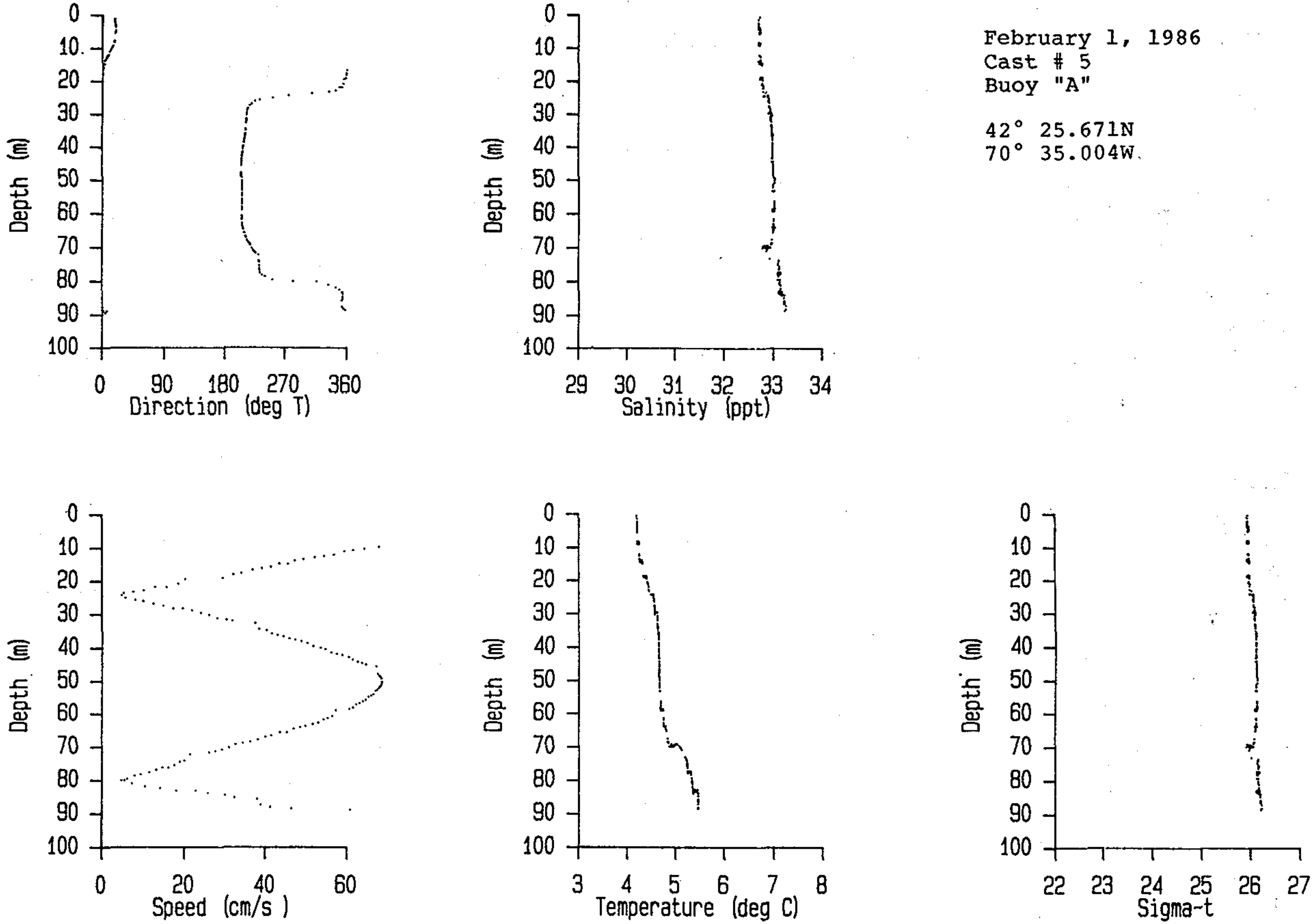


Figure I-1 continued

February 1, 1986
Cast # 6
"A" Buoy
42° 25.671N
70° 35.004W

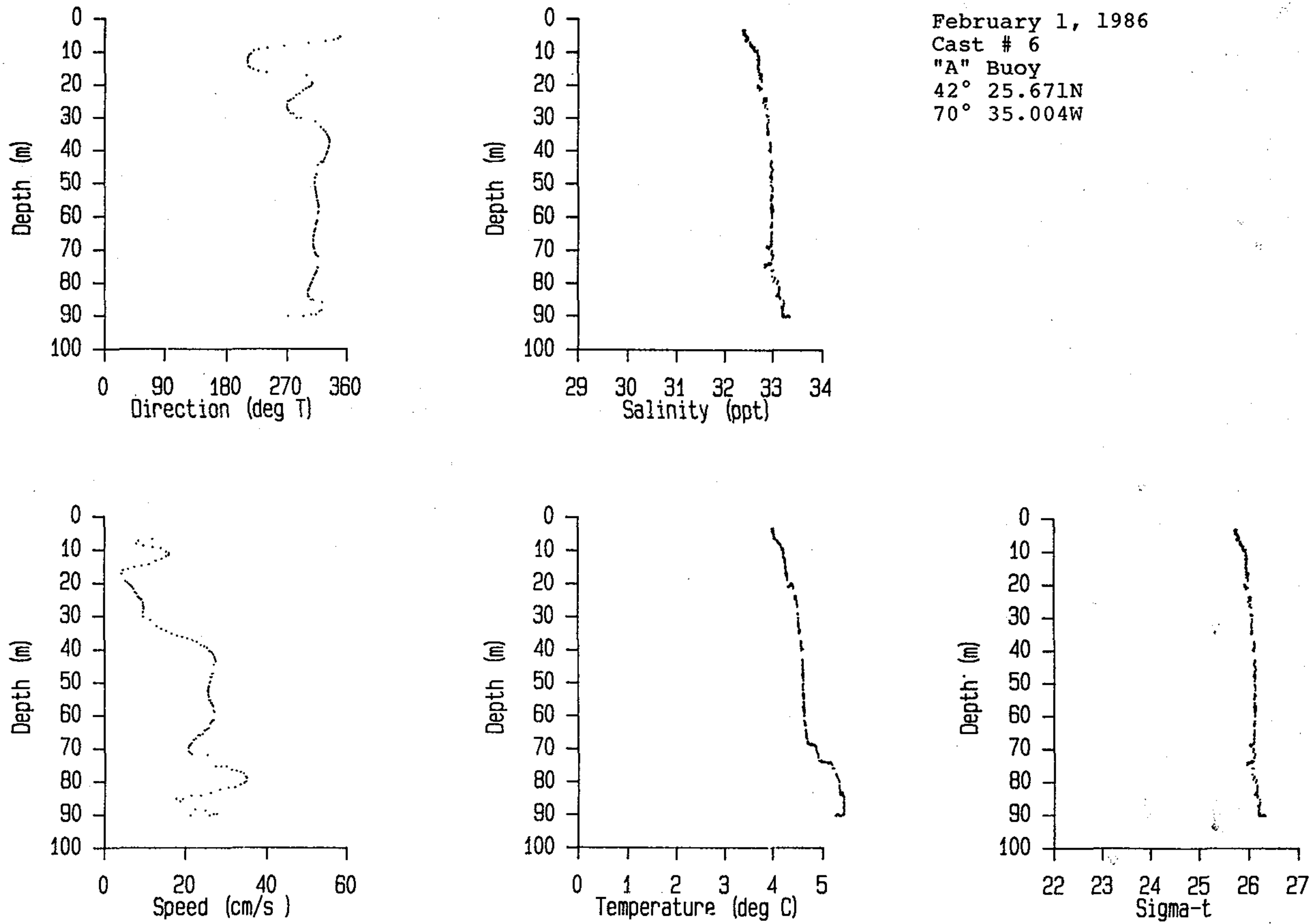


Figure I-1 continued

February 14, 1986

42° 25.400N
70° 32.995W

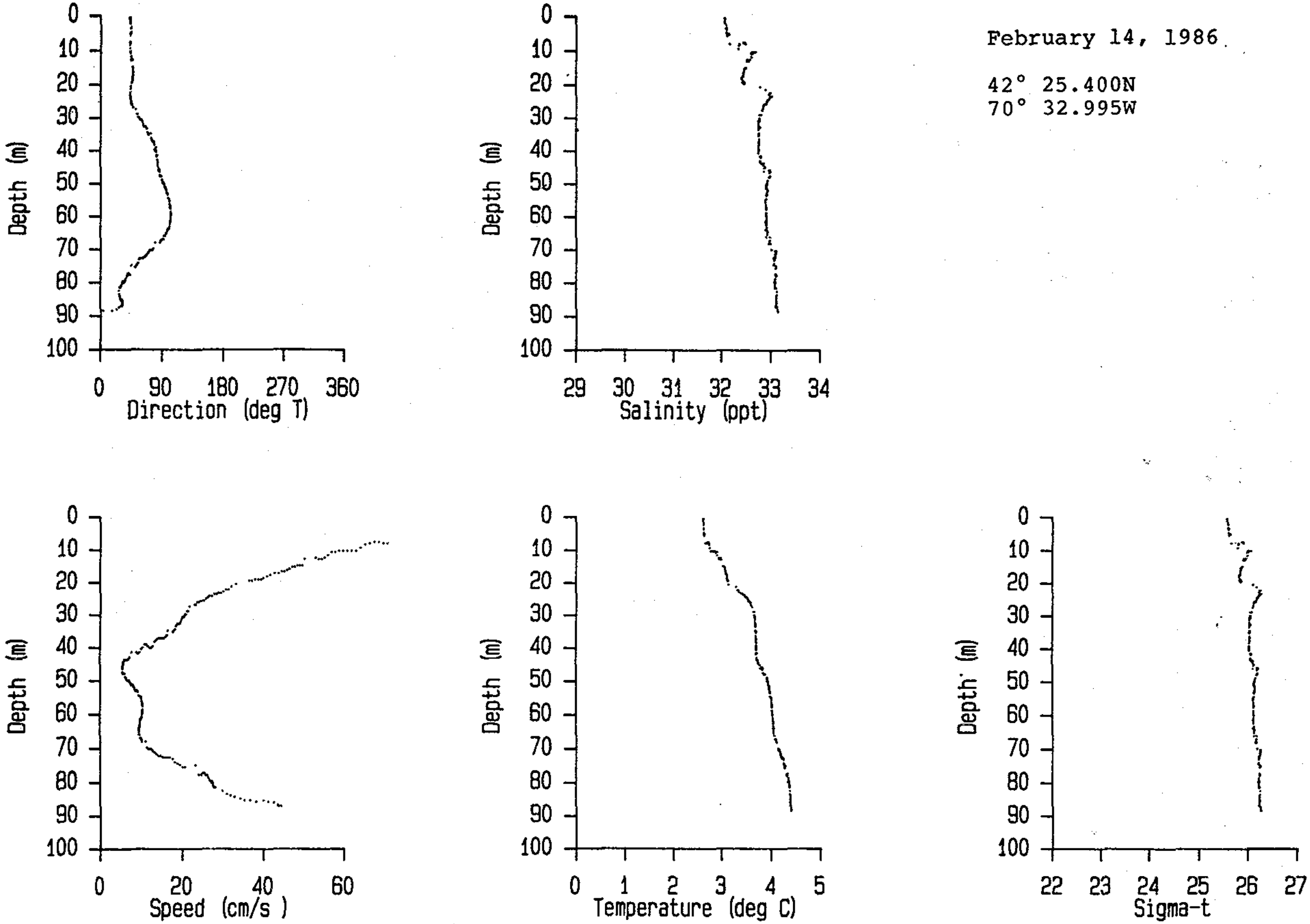


Figure I-1 continued

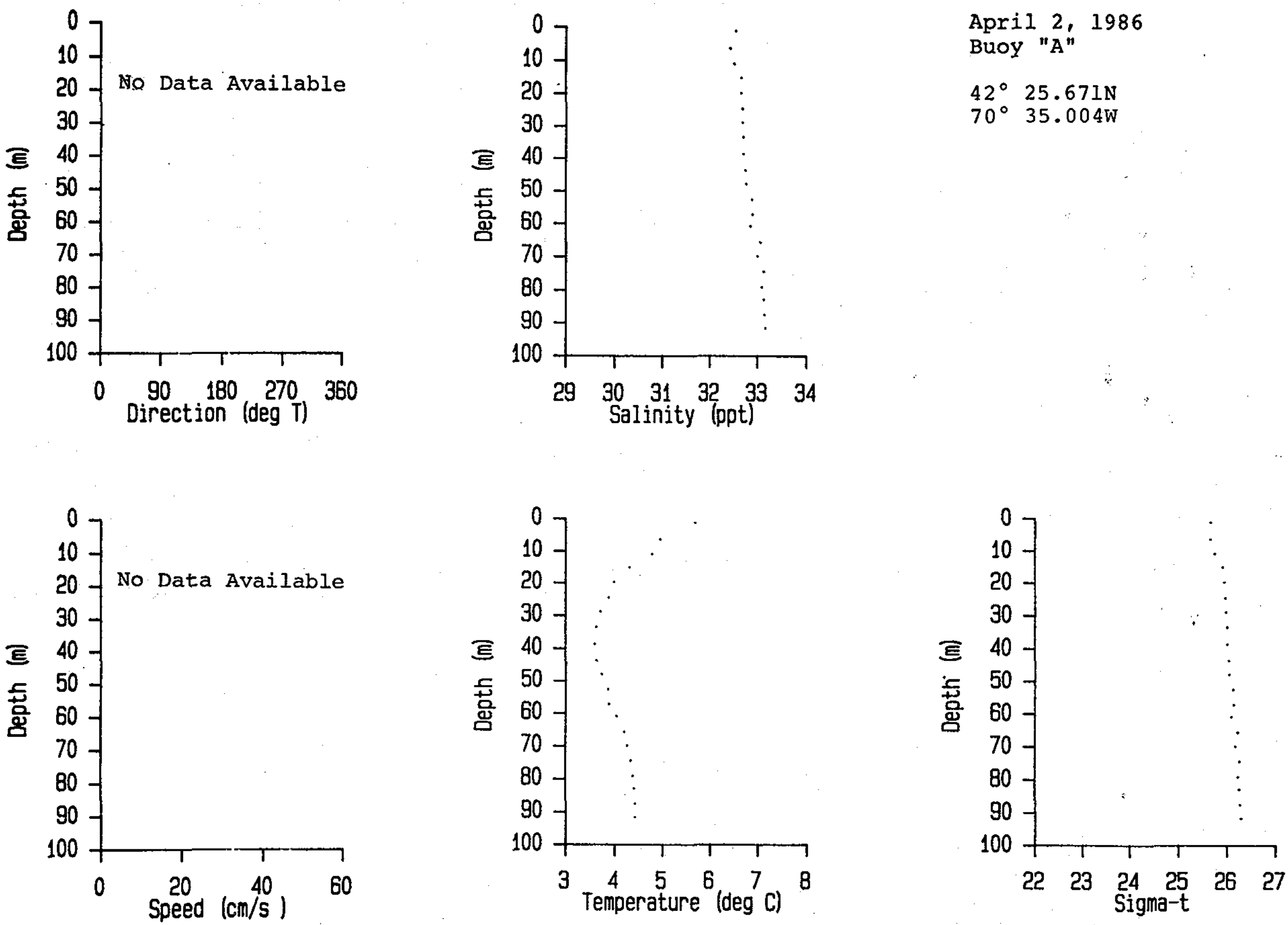


Figure I-1 continued

Results Of The Bivariate Analysis Of 3-HLP Current Meter Data Collected At FADS At A Depth Of 10m For The Period Of Sep 20 - Oct 18, 1985

FREQUENCY DISTRIBUTION
1.00 HOURLY DATA   STATION: FAD21   3HRLP   SPANNING 9/20/85 TO 10/18/85   674 DATA POINTS

DIRECTION DEGREES									PERCENT	MEAN SPEED	MIN SPEED	MAX SPEED	STD. DEV.
0- 30	.4	4.0	5.0	1.8	.1	.0	.1	.3	11.9	23.34	5.10	77.44	14.24
30- 60	.9	2.4	10.4	5.5	.7	.1	.1	.0	20.2	27.18	5.36	65.87	8.50
60- 90	1.3	2.8	8.3	4.5	.1	.0	.0	.0	17.1	24.40	3.62	49.30	9.28
90-120	.3	1.2	3.3	.6	.3	.0	.0	.0	5.6	23.72	2.46	48.25	9.26
120-150	.0	1.6	2.1	.6	.0	.1	.0	.0	4.5	23.06	11.80	58.98	10.50
150-180	.1	2.1	1.2	.6	.1	.3	.1	.0	4.6	25.00	7.63	60.55	14.14
180-210	.7	1.9	1.6	.6	.6	.3	.0	.0	5.8	22.74	.43	53.82	15.22
210-240	1.2	2.2	1.2	1.2	.1	.1	.0	.0	6.1	20.20	3.50	53.23	12.93
240-270	1.8	2.4	.6	.6	.1	.0	.0	.0	5.5	15.72	2.11	43.50	10.78
270-300	2.1	3.0	2.7	.1	.0	.0	.0	.0	7.9	16.42	1.60	30.82	7.63
300-330	.9	3.0	1.3	.3	.0	.0	.0	.0	5.5	16.87	5.95	32.84	7.81
330-360	1.2	3.3	1.0	.0	.0	.0	.0	.0	5.5	15.47	2.10	28.29	4.30
SPEED	0	10	20	30	40	50	60	70					
	!	!	!	!	!	!	!	!					
CM/S	10	20	30	40	50	60	70	80					
PERCENT	11.0	29.8	38.7	16.3	2.4	1.0	.4	.3	100.00				
MEAN DIR	214	183	111	94	123	161	64	9					
STD DEV	104	114	93	74	79	59	93	17					

SUMMARY STATISTICS

MEAN SPEED = 22.41 CM/S   MAXIMUM = 77.44 CM/S   MINIMUM = .43 CM/S   RANGE = 77.01 CM/S
STANDARD DEVIATION = 10.60 CM/S   SKEWNESS = .89

IN A COORDINATE SYSTEM WHOSE Y AXIS IS POSITIONED .00 DEGREES CLOCKWISE FROM TRUE NORTH
MEAN X COMPONENT = 6.86 CM/S   STANDARD DEVIATION = 16.46 CM/S   SKEWNESS = -.24
MEAN Y COMPONENT = 4.89 CM/S   STANDARD DEVIATION = 16.52 CM/S   SKEWNESS = -.45

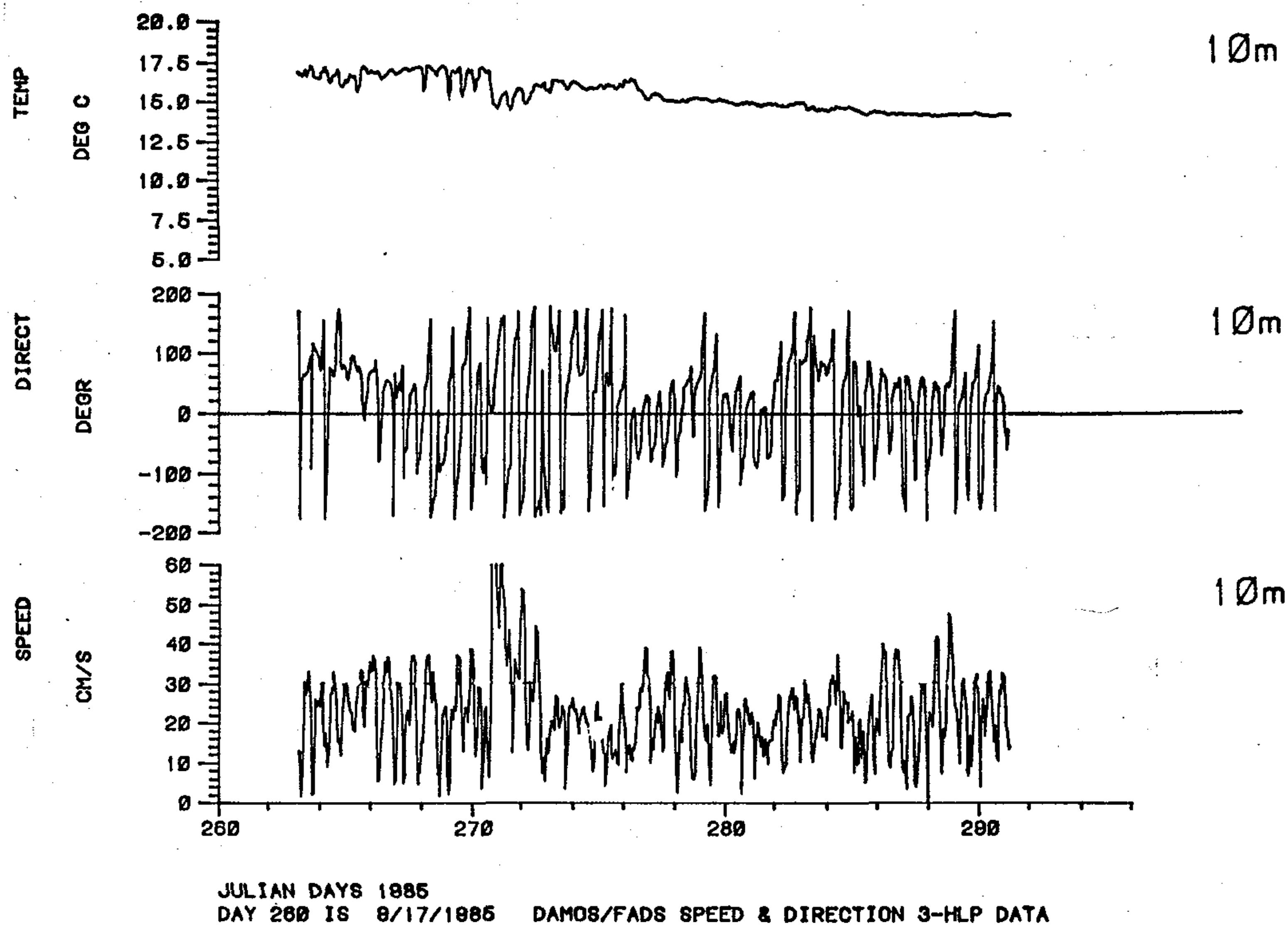


Figure I-2 Three-hour low pass (3-HLP) time series of temperature, current speed and direction at FADS, at a depth of 10m for the period of Sep 20 - Oct 18, 1985.

Table I-2

Results Of The Bivariate Analysis Of 3-HLP Current Meter Data Collected At FADS At A Depth Of 82m (4m from the bottom) For The Period Of September 20 - October 18, 1985

FREQUENCY DISTRIBUTION
1.00 HOURLY DATA   STATION: FAD24   3HRLP   SPANNING 9/20/85 TO 10/18/85   675 DATA POINTS

DIRECTION DEGREES	0 ! 4	4 ! 8	8 ! 12	12 ! 16	16 ! 20	20 ! 24	24 ! 28	PERCENT	MEAN SPEED	MIN SPEED	MAX SPEED	STD. DEV.
0- 30	2.8	1.2	.3	.9	.6	.0	.0	5.8	6.59	.43	17.88	5.95
30- 60	2.5	.7	.1	1.6	1.0	.1	.0	6.2	8.61	.21	20.33	7.23
60- 90	4.1	1.2	.3	.7	1.9	.1	.0	8.4	7.43	.11	21.98	7.48
90-120	5.8	3.4	2.1	1.5	1.9	.9	.0	15.6	8.13	.10	21.31	6.59
120-150	3.9	.6	.7	.9	.9	.9	.0	7.9	8.35	.17	23.06	7.69
150-180	2.4	.3	.1	.3	.1	.1	.0	3.4	5.63	.38	23.59	5.67
180-210	2.8	.4	.1	.0	.1	.0	.0	3.6	3.09	.35	16.36	4.06
210-240	4.4	.6	.1	.3	.4	.0	.0	5.9	4.37	.02	19.65	4.97
240-270	5.2	2.2	.0	.6	1.3	.4	.1	9.9	6.86	.23	24.59	7.13
270-300	7.4	4.3	1.0	2.2	3.6	1.8	.0	20.3	9.02	.43	23.39	7.34
300-330	4.0	.6	.4	.6	1.5	.1	.0	7.3	7.38	.17	20.08	7.06
330-360	3.7	.4	.0	.9	.7	.0	.0	5.8	5.65	.23	18.57	6.80
SPEED CM/S	0 ! 4	4 ! 8	8 ! 12	12 ! 16	16 ! 20	20 ! 24	24 ! 28					
PERCENT	49.0	16.0	5.5	10.5	14.2	4.6	.1	100.00				
MEAN DIR	193	187	160	171	194	199	265					
STD DEV	102	99	90	115	106	91	0					

SUMMARY STATISTICS

MEAN SPEED = 7.40 CM/S   MAXIMUM = 24.59 CM/S   MINIMUM = .02 CM/S   RANGE = 24.57 CM/S
STANDARD DEVIATION = 6.88 CM/S   SKEWNESS = .78

IN A COORDINATE SYSTEM WHOSE Y AXIS IS POSITIONED .00 DEGREES CLOCKWISE FROM TRUE NORTH
MEAN X COMPONENT = -.33 CM/S   STANDARD DEVIATION = 8.64 CM/S   SKEWNESS = -.16
MEAN Y COMPONENT = .55 CM/S   STANDARD DEVIATION = 5.18 CM/S   SKEWNESS = .21

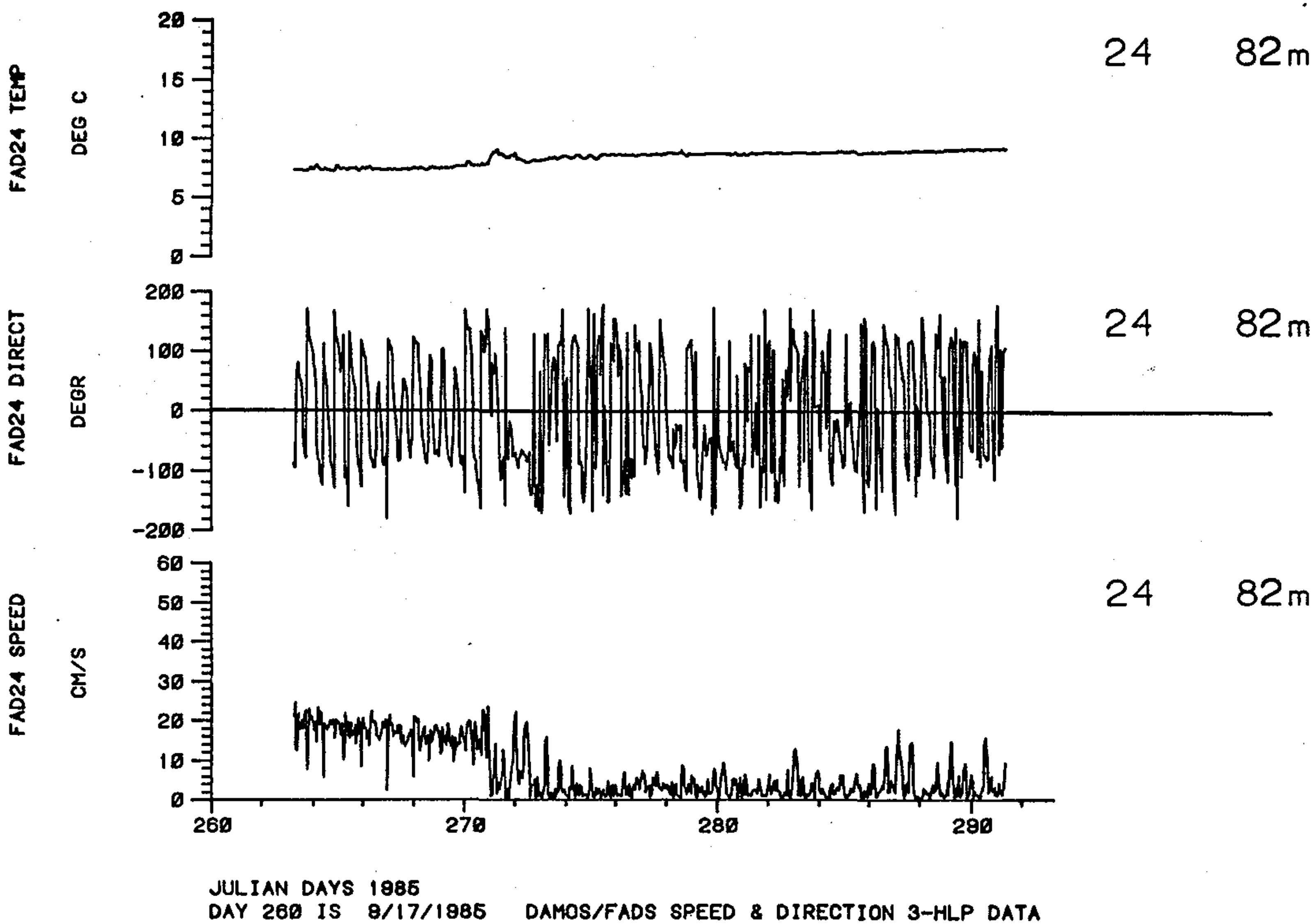


Figure I-3 Three-hour low pass (3-HLP) time series of temperature, current speed and direction at FADS at a depth of 80m (4m from the bottom) for the period of Sep 20 - Oct 18, 1985.

Table I-3

Results Of The Bivariate Analysis Of 3-HLP Current Meter Data Collected At FADS At A Depth Of 85m For The Period Of Sept. 20 - Oct. 18, 1985

FREQUENCY DISTRIBUTION
1.00 HOURLY DATA   STATION: FAB31   3HRLP   SPANNING 2/15/86 TO 4/ 2/86   1111 DATA POINTS

DIRECTION DEGREES												PERCENT	MEAN SPEED	MIN SPEED	MAX SPEED	STD. DEV.
0- 30	4.0	.6	.0	.0	.0	.0	.0	.0	.0	.0	.0	4.6	2.98	.16	6.73	2.08
30- 60	5.5	.9	.0	.0	.0	.0	.0	.0	.0	.0	.0	6.4	2.90	.15	7.12	2.23
60- 90	7.5	.8	.0	.0	.0	.0	.0	.0	.0	.0	.0	8.3	2.94	.11	8.92	1.59
90-120	14.0	3.8	.5	.1	.0	.0	.0	.0	.0	.0	.0	18.5	3.95	.21	16.14	2.61
120-150	10.4	3.3	.1	.0	.0	.0	.0	.0	.0	.0	.0	13.9	3.72	.13	10.72	2.33
150-180	4.1	1.5	.0	.0	.0	.0	.0	.0	.0	.0	.0	5.6	3.62	.09	7.34	2.65
180-210	6.2	1.2	.1	.4	.0	.2	.0	.0	.1	.0	.0	8.1	4.94	.21	40.16	6.42
210-240	4.9	1.2	.6	.4	.0	.0	.2	.1	.1	.4	.2	7.9	9.43	.22	54.56	13.31
240-270	6.1	.3	.3	.1	.0	.0	.0	.0	.0	.0	.0	6.8	3.15	.17	17.27	2.90
270-300	7.6	1.2	.7	.1	.0	.0	.0	.0	.0	.0	.0	9.5	3.91	.33	16.50	3.37
300-330	5.9	.9	.1	.0	.0	.0	.0	.0	.0	.0	.0	6.8	3.03	.11	10.55	2.38
330-360	3.2	.5	.0	.0	.0	.0	.0	.0	.0	.0	.0	3.7	3.29	.17	7.11	1.68

SPEED	0	5	10	15	20	25	30	35	40	45	50	
	!	!	!	!	!	!	!	!	!	!	!	
CM/S	5	10	15	20	25	30	35	40	45	50	55	
PERCENT	79.2	16.2	2.4	1.0	.0	.2	.2	.1	.2	.4	.2	100.00
MEAN DIR	169	158	218	210	0	192	215	211	209	213	212	
STD DEV	93	84	72	51	0	44	94	0	38	84	1081	

SUMMARY STATISTICS

MEAN SPEED = 4.07 CM/S   MAXIMUM = 54.56 CM/S   MINIMUM = .09 CM/S   RANGE = 54.47 CM/S
STANDARD DEVIATION = 4.90 CM/S   SKEWNESS = 6.04

IN A COORDINATE SYSTEM WHOSE Y AXIS IS POSITIONED .00 DEGREES CLOCKWISE FROM TRUE NORTH
MEAN X COMPONENT = .21 CM/S   STANDARD DEVIATION = 4.18 CM/S   SKEWNESS = -2.04
MEAN Y COMPONENT = -1.09 CM/S   STANDARD DEVIATION = 4.68 CM/S   SKEWNESS = -5.14

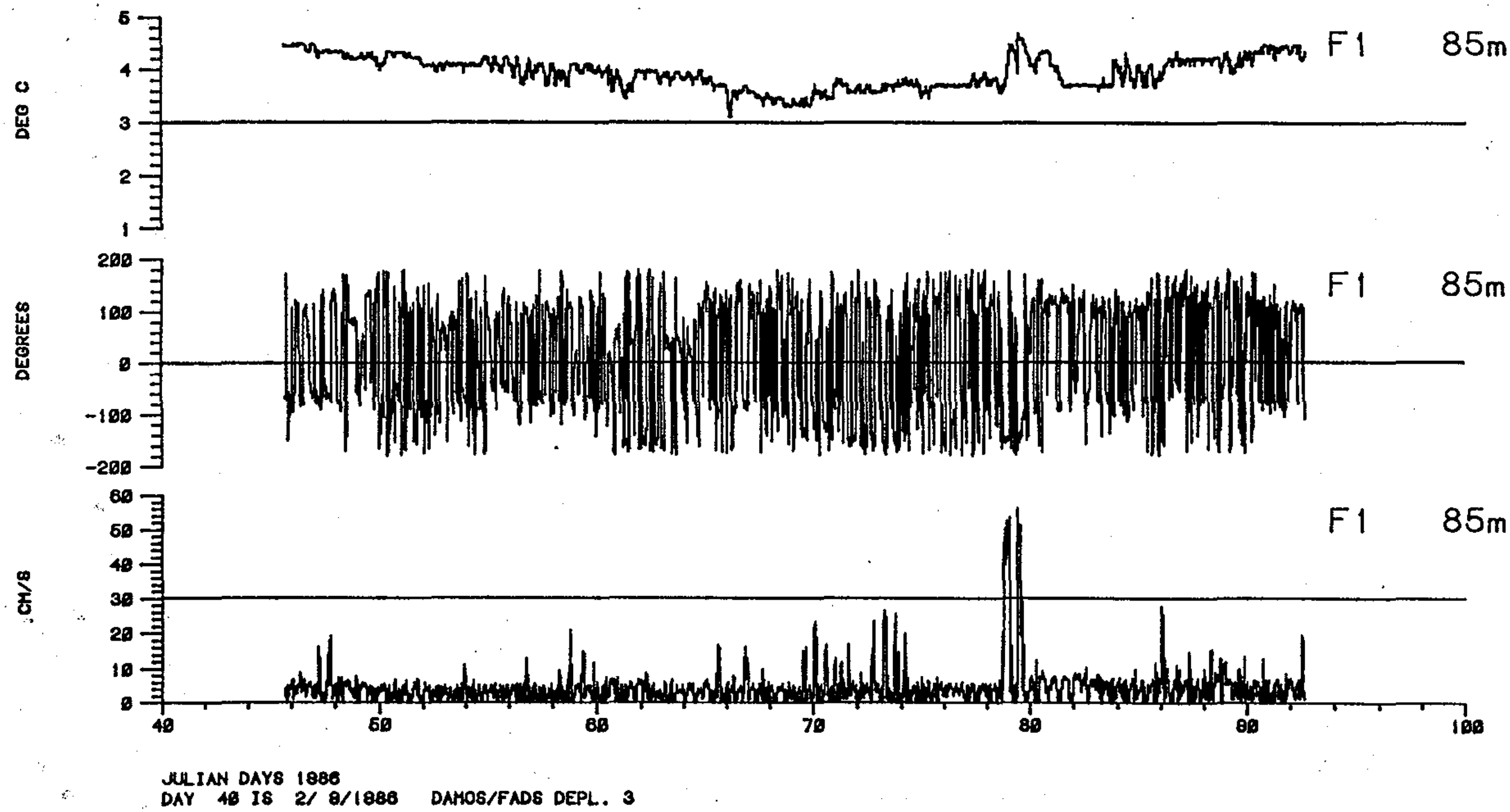


Figure I-4. Three-hour low pass (3-HLP) time series of temperature, current speed and direction at FADS, at a depth of 85m for the period of Sept. 20 - Oct. 18, 1985.